U.S. Department of Energy
National Nuclear Security Administration
Livermore Site Office, Livermore, California 94551

Lawrence Livermore National Laboratory
Lawrence Livermore National Security, LLC, Livermore, California 94551

LLNL-AR-553611-DRAFT

Draft Five-Year Review Report for the High Explosives Process Area Operable Unit at Lawrence Livermore National Laboratory Site 300

Authors:

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May 2012

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Environmental Restoration Department

This work performed under the auspices of the U. S. Department of Energy/National Nuclear Security Administration by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Certification

I certify that the work presented in this report was performed under my supervision. To the best of my knowledge, the data contained herein are true and accurate, and the work was performed in accordance with professional standards.

Victor Madrid Date
California Professional Geologist
No. 5051
License expires: April 30, 2014
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No. 378
License expires: April 30, 2014

Approval for the Five-Year Review for the High Explosives Process Area Operable Unit at Lawrence Livermore National Laboratory Site 300

Prepared by:

United States Department of Energy
National Nuclear Security Administration
Livermore Site Office
Livermore, California

Approved:

Claire S. Holtzapple **Date**

Site 300 Remedial Project Manager
U.S. Department of Energy
National Nuclear Security Administration
Livermore Site Office

Five-Year Review Summary Form

Site Identification		
Site name: Lawrence Livermore National Laboratory Site 300, High Explosives Process Area Operable Unit (OU)		
EPA ID: CA 2890090002		
Region: IX	State: California	City/County: San Joaquin/Alameda
Site Status		
NPL status: Final		
Remediation status: Operating		
Multiple OUs: Yes	Construction completion date: September 2007	
Has the site been put into reuse: No		
1.0 REVIEW STATUS		
Reviewing agency: U.S. Department of Energy/National Nuclear Security Administration		
Author name: A. Helmig		
Author title: Hydrogeologist	Author affiliation: Weiss Associates- Emeryville, California	
Review period: September 2006 to September 2011		
Date(s) of site inspection: March 31, 2011		
Type of review: Statutory		
Review number: 2		
Triggering action: 2007 Five-Year Review for the High Explosives Process Area OU		
Triggering action date: September 7, 2007		
Due date: May 9, 2012		

Five-Year Review Summary Form (continued)

Deficiencies:

No deficiencies in the remedy were identified during this evaluation.

Recommendations and Follow-up Actions:

The following recommendations were developed during the review process and will be carried out by the United States (U.S.) Department of Energy (DOE)/National Nuclear Security Administration (NNSA):

1. Install one new extraction well (W-815-2803) to increase hydraulic capture and mass removal in the Building 815 source area and to prevent migration of volatile organic compounds (VOCs), high explosive (HE) compounds, and perchlorate in the $Tnbs_2$ hydrostratigraphic unit (HSU). This extraction well will be connected to the Building 815-Source (815-SRC) treatment facility. The well is scheduled to be drilled in 2012 and will be connected to 815-SRC in 2014.
2. Convert $Tnbs_2$ HSU monitor well W-815-2608 to an extraction well to increase hydraulic capture and prevent offsite migration of VOCs, and connect it to the 815-Distal Site Boundary (DSB) ground water treatment system. The well is scheduled to be connected to the 815-DSB facility in 2012.
3. Evaluate $Tnbs_2$ HSU monitor well W-815-2621 to determine its suitability as an extraction well for the 815-DSB wellfield.
4. Install one new well (W-817-2XM1) to monitor HE compounds, perchlorate, and nitrate concentrations near the 817-SRC treatment facility in the $Tnbs_2$ HSU. This monitor well will assess the effectiveness of the 817-SRC recirculation cell between extraction well W-817-01 and effluent injection well W-817-06A. This well is scheduled to be drilled in 2014.
5. Install one new well (W-815-2XM1) to monitor VOCs, HE compounds, perchlorate, and nitrate concentrations near the Building 815 source area in the Tpsg-Tps HSU. This well is scheduled to be drilled in 2014.
6. Over the next five-years:
    - Evaluate $Tnbs_2$ HSU well W-817-2609 in the 817-Proximal area by monitoring contaminant concentrations in this well and nearby well W-817-03 to determine whether to convert well W-817-2609 to an extraction well.
    - Identify potential locations for two additional effluent injection wells to allow 817-PRX wellfield extraction rates to be increased in the $Tnbs_2$ HSU.

Operation of and hydraulic capture zones for existing and new extraction wells in the HEPA OU will be evaluated over the next five years and documented in the Annual Compliance Monitoring Reports. Based on these data, DOE/NNSA will pursue opportunities to optimize wellfield operations to maximize contaminant removal as they are identified. No other follow-up

actions were identified related to this Five-Year Review. As discussed below, these recommendations do not affect the protectiveness of the remedy.

Protectiveness Statement:

The remedy at the High Explosives Process Area (HEPA) Operable Unit (OU) is protective of human health and the environment for the site's industrial land use. The remedy protects human health because exposure pathways that could result in unacceptable risk to onsite workers are being controlled by the implementation of institutional controls, the Health and Safety Plan, and the Contingency Plan.

The cleanup standards for HEPA OU ground water are drinking water standards. Because drinking water standards do not differentiate between industrial and residential use, the ground water cleanup remedy will be protective under any land use scenario.

The cleanup standards for volatile organic compounds (VOCs) in subsurface soil are to reduce concentrations to mitigate risk to onsite workers and prevent further impacts to ground water to the extent technically and economically feasible. Because some VOCs may remain in subsurface soil following the achievement of these cleanup standards, a land use control prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition is included in the Site-Wide Record of Decision. This prohibition will remain in place until and unless a risk assessment is performed in accordance with current U.S. Environmental Protection Agency (EPA) risk assessment guidance and is agreed by the DOE/NNSA, the EPA, the California Department of Toxic Substances Control and the Regional Water Quality Control Board as adequately showing no unacceptable risk for residential or unrestricted land use.

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1. Introduction

The United States (U.S.) Department of Energy (DOE)/National Nuclear Security Administration (NNSA) has conducted a Five-Year Review of the remedial actions implemented at the High Explosives Process Area (HEPA) Operable Unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300. Environmental cleanup is conducted under the oversight of the U.S. Environmental Protection Agency (EPA), the California Department of Toxic Substances Control (DTSC), and the California Regional Water Quality Control Board (RWQCB) – Central Valley Region. DOE/NNSA is the lead agency for environmental restoration at LLNL. The review documented in this report was conducted from September 2006 through September 2011. Parties providing analyses in support of the review include:

- U.S. DOE/NNSA, Livermore Site Office.
- LLNL, Environmental Restoration Department (ERD).
- Weiss Associates.

The purpose of a Five-Year Review is to evaluate the implementation and performance of a remedy to determine whether the remedy will continue to be protective of human health and the environment. The Five-Year Review report presents the methods, findings, and conclusions of the review. In addition, the Five-Year Review identifies issues or deficiencies in the selected remedy, if any, and presents recommendations to address them. The format and content of this document is consistent with guidance issued by DOE (DOE, 2002) and the U.S. EPA (EPA, 2001).

Section 121 of the Comprehensive Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendment Reauthorization Act (SARA), requires that remedial actions that result in any hazardous substances, pollutants, or contaminants remaining at the site be subject to a Five-Year Review. The National Contingency Plan further provides that remedial actions which result in any hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure be reviewed every five years to ensure protection of human health and the environment. Consistent with Executive Order 12580, Federal agencies are responsible for ensuring that Five-Year Reviews are conducted at sites where five-year reviews are required or appropriate.

LLNL Site 300 (Figure 1) has been divided into nine Operable Units (OUs) based on the nature and extent of contamination to effectively manage site cleanup (Figure 2):

- General Services Area (GSA) (OU 1) including the Central and Eastern GSA.
- Building 834 (OU 2).
- Pit 6 Landfill (OU 3).
- High Explosives (HE) Process Area (OU 4) including Building 815, the HE Lagoons, and the HE Burn Pit.
- Building 850/Pit 7 Complex (OU 5).
- Building 854 (OU 6).
- Building 832 Canyon (OU 7) including Buildings 830 and 832.

- Site-Wide (OU 8) including Buildings 801, 833, 845, and 851 and the Pit 2, 8, 9 Landfills.
- Building 812 (OU 9).

Five-year reviews are conducted individually for each OU at Site 300, except for OUs 3 and 8. The Construction Completion Report (Holtzapple, 2008) and Site-Wide Record of Decision (ROD) (U.S DOE, 2008) are the triggers for the five-year reviews for OUs 3 and 8, respectively, in accordance with EPA guidance. At the other OUs where construction began prior to the Site-Wide ROD as treatability studies and/or removal actions, DOE/NNSA and the regulatory agencies agreed to use the completion of the OU-specific Remedial Design reports as the triggers for the first five-year reviews.

This is the second Five-Year Review for the HEPA OU (OU 4). The first Five-Year Review was completed in 2007 (Dibley et al., 2007b). This review is considered a statutory review because: (1) contamination will remain onsite upon completion of the remedial action, (2) the Record of Decision was signed after October 17, 1986 (the effective date of the SARA), and (3) the remedial action was selected under the CERCLA. The triggering action for the first review was the August 15, 2002 submittal date of the Interim Remedial Design for the High Explosives Process Area Operable Unit at Lawrence Livermore National Laboratory Site 300 (Madrid et al., 2002).

The background and description of the HEPA OU are presented in Section 3. The following sections include the descriptions and status of the other OUs and areas where environmental restoration activities are occurring at Site 300.

1.1. General Services Area (GSA) OU (OU 1)

The GSA OU has been separated into the Central GSA and the Eastern GSA based on differences in hydrogeology and the distribution of environmental contaminants. DOE/NNSA has performed three Five-Year Reviews for the GSA OU (Ferry et al., 2001b; Dibley et al., 2006a; and Valett et al., 2011). The fourth Five-Year Review is scheduled for 2016.

1.1.1. Central GSA

Chlorinated solvents, mainly trichloroethene (TCE), were used as degreasing agents in craft shops in the Central GSA. Rinse water from these degreasing operations was disposed of in dry wells that were gravel-filled holes about 3 to 4 feet (ft) deep and 2 ft in diameter. As a result, subsurface soil and ground water were contaminated with volatile organic compounds (VOCs). There are no contaminants of concern (COCs) in surface soil in the central GSA. The Central GSA dry wells were used until 1982. In 1983 and 1984, these dry wells were decommissioned and excavated.

Ground water cleanup began in the Central GSA in 1992 and soil vapor extraction started in 1994 as removal actions. In 1997, a Final ROD for the GSA OU (U.S. DOE, 1997) was signed and ground water and soil vapor extraction and treatment continued as a remedial action. The selected remedy for the Central GSA includes monitoring, risk and hazard management, and ground water and soil vapor extraction and treatment. The remedial design was completed in 1998 and construction completion for the OU was documented in September 2005.

Operation of the ground water and soil vapor extraction and treatment systems to remove VOCs from the subsurface is ongoing. Remediation has reduced maximum VOC concentrations in ground water from 272,000 micrograms per liter (µg/L) to 700 µg/L (April 2011) and has mitigated the risk to onsite workers from inhalation of VOCs inside Building 875.

1.1.2. Eastern GSA

The source of contamination in the Eastern GSA is an abandoned debris burial trench that received craft shop debris. Leaching of solvents from the debris resulted in the release of VOCs to ground water.

Ground water cleanup began in the Eastern GSA in 1991 as a removal action. In 1995, a Final ROD for the GSA OU was signed and ground water extraction and treatment continued as a remedial action. The remedial design was completed in 1998 and construction completion for the OU was documented in September 2005. A ground water extraction and treatment system operated from 1991 to 2007 to remove VOCs from ground water.

By 2005, VOC concentrations in both onsite and offsite ground water in the Eastern GSA area had been reduced to below the drinking water MCL cleanup standards. In February 2007, the ground water extraction and treatment system was shut down with regulatory concurrence. DOE/NNSA continued to monitor ground water for five years, during which time VOC concentrations remained below the MCL cleanup standards, indicating that ground water cleanup had been successfully completed in the Eastern GSA.

1.2. Building 834 (OU 2)

From 1962 to 1978, intermittent spills and piping leaks resulted in contamination of the subsurface soil and rock and ground water with VOCs and silicone oils (tetrabutyl orthosilicate/tetrakis (2-ethylbutyl) silane [TBOS/TKEBs]). Nitrate in ground water results from septic system effluent but may also have natural sources. There are no COCs in surface soil.

Completed remedial activities include excavating VOC-contaminated soil (1983) and installing a surface water drainage diversion system to prevent rainwater infiltration in the contaminant source area (1998). Ground water and soil vapor extraction and treatment began in 1986 as treatability studies. An area-specific Interim ROD for the Building 834 OU (U.S. DOE, 1995) was superseded by the Interim Site-Wide ROD and subsequent 2008 Site-Wide ROD. The Building 834 OU remedy includes monitoring, risk and hazard management, and ground water and soil vapor extraction and treatment. Significant *in situ* bioremediation is occurring in Building 834 ground water and a treatability study focusing on understanding and enhancing this process has been conducted. The remedial design was completed in 2002 and construction completion for the OU was achieved in September 2005.

Remediation has reduced VOC concentrations in ground water from a historical maximum of 1,060,000 µg/L to a maximum of 210,000 µg/L in February 2011. TBOS/TKEBs in ground water has also been reduced from a historic maximum concentration of 7,300,000 µg/L in 1995 to 4,800 µg/L (February 2011). While nitrate concentrations have decreased from a historic maximum of 749 milligrams per liter (mg/L) in 2000 to 300 mg/L (February 2011), the continued elevated nitrate concentrations indicate an ongoing source of ground water nitrate. It is likely that there are multiple sources of nitrate at Building 834. One possible anthropogenic source is the septic system leachfield located in the vicinity of wells W-834-S1. A second

probable source is natural soil nitrate. Additional sources could be nitrogenous compounds, like nitric acid or barium nitrate, that might have inadvertently been discharged into the septic system via a test cell floor drain or to the ground during accidental spills and/or pipeline leaks that released TCE to the environment. Anaerobic bacteria in the Building 834 Core and T2 areas reduce nitrate locally by denitrification.

DOE/NNSA has performed three Five-Year Reviews for the Building 834 OU (Ferry et al., 2002a, Dibley et al., 2007a, and Valett et al., 2012).

1.3. Pit 6 Landfill (OU 3)

From 1964 to 1973, approximately 1,900 cubic yards (yd^3) of waste from LLNL Livermore Site and Lawrence Berkeley Laboratory was buried in nine unlined trenches and animal pits at the Pit 6 Landfill. Infiltrating rainwater leached contaminants from pit waste resulting in tritium, VOC, and perchlorate contamination in ground water. Nitrate contamination in ground water results from septic system effluent. No COCs were identified in surface or subsurface soil.

In 1971, DOE excavated portions of the waste contaminated with depleted uranium. In 1997, a landfill cap was installed as a CERCLA removal action to prevent infiltrating precipitation from further leaching contaminants from the waste. Because of decreasing VOC concentrations in ground water, the presence of trichloroethene (TCE) degradation products, and the short half-life of tritium (12.3 years), the selected remedy for VOCs and tritium at the Pit 6 Landfill is monitored natural attenuation (MNA). Because ground water monitoring data for perchlorate and nitrate are limited, DOE/NNSA will continue to monitor ground water to determine if and when an active remedy for these contaminants might be necessary. The remedy also includes risk and hazard management. Construction completion was achieved in October 2002. No Remedial Design document was required for this area.

The extent of contamination at the Pit 6 Landfill is limited and continues to decrease with concentrations/activities near and below cleanup standards. Natural attenuation has reduced total VOCs in ground water from a historic maximum of 250 µg/L in 1988 to a first semester 2011 maximum concentration of 9.3 µg/L (April 2011). Tritium activities are well below the cleanup standard and continue to decrease towards background levels. Perchlorate is not currently detected in any wells above the 4 µg/L reporting limit. The extent of nitrate at concentrations exceeding the cleanup standard continues to be limited to one well. Installation of the landfill cap mitigated the onsite worker inhalation risk.

The first Five-Year Review for this OU is scheduled for 2012.

1.4. Building 850/Pit 7 Complex (OU 5)

This OU has been divided into two areas for cleanup evaluation purposes: (1) the Building 850 Firing Table area, and (2) the Pit 7 Complex.

A Remedial Action Completion Report for the Building 850/Pit 7 Complex OU was completed in 2011 (Dibley et al., 2011b). The first Five-Year Review for this OU is scheduled for 2016.

1.4.1. Building 850 Firing Table (OU 5)

High-explosives experiments were conducted at the Building 850 Firing Table from 1958 to 2008. Tritium was used in some of these experiments, primarily between 1963 and 1978. As a result of the destruction and dispersal of test assembly debris during detonations, surface soil was contaminated with metals, polychlorinated biphenyls (PCBs), dioxins, furans, High-Melting Explosive (HMX), and depleted uranium. Leaching from firing table debris has resulted in tritium and depleted uranium contamination in subsurface soil and ground water. Nitrate and perchlorate are also COCs in ground water. Tritium is the only COC in surface water (Well 8 Spring).

Gravel was removed from the firing table in 1988 and placed in the Pit 7 Landfill. PCB-contaminated shrapnel and debris were removed from the area around the firing table in 1998. The Building 850 remedy consists of MNA, monitoring, and risk and hazard management. A remedial design was completed in 2004. The remedial design included the excavation and offsite disposal of contaminated surface soil and sand pile. This remedy was not implemented due to a large increase in transportation and offsite disposal costs. DOE and the regulatory agencies agreed to perform remediation of contaminated surface soil as a non-time critical removal action. An Engineering Evaluation/Cost Analysis (Dibley et al., 2008a) and Action Memorandum (Dibley et al., 2008b) were completed in 2008. A removal action was completed in 2010 for the excavation and solidification of PCB-, dioxin-, and furan-contaminated soil and sand pile. Metals, HMX, and uranium in surface soil at Building 850 do not pose a risk to human health or threat to ground water, therefore a no further action remedy was selected. However, these constituents in surface soil were removed during the soil excavation/solidification removal action.

Natural attenuation has reduced tritium activities from a historic maximum of 566,000 picoCuries per liter (pCi/L) in 1985 to a first semester 2011 maximum of 53,300 pCi/L (May 2011). Uranium activities are below the cleanup standard and are within the range of natural background levels. The extent of nitrate with concentrations above cleanup standards is limited and does not pose a threat to human health or the environment. The maximum perchlorate concentration in the first semester 2011 is 74 µg/L (April 2011), and a treatability study to evaluate *in situ* biodegradation of perchlorate is in progress.

1.4.2. Pit 7 Landfill Complex (OU 5)

The Pit 3, 4, 5, and 7 Landfills are collectively designated the Pit 7 Landfill Complex. Firing table debris containing tritium, depleted uranium, and metals was placed in the pits in the 1950s through the 1980s. The Pit 4 and 7 Landfills were capped in 1992. During years of above-normal rainfall (i.e., 1997-1998 El Niño event), ground water rose into the bottom of the landfills and the underlying contaminated bedrock. This resulted in the release of tritium, uranium, VOCs, perchlorate, and nitrate to ground water. There are no COCs in surface water or surface soil. Tritium and depleted uranium are COCs in subsurface soil.

DOE and the regulatory agencies agreed that the Pit 7 Complex required additional study; accordingly, this area was not included in the 2001 Interim ROD and an area-specific Remedial Investigation/Feasibility Study (Taffet et al., 2005) was completed. An Amendment to the Interim ROD for the Pit 7 Complex was signed in 2007 (U.S. DOE, 2007) that described the selected remedy for the Pit 7 Complex including monitoring, risk and hazard management,

MNA, ground water extraction and treatment, and source control. The interim remedial design was completed in 2008. A hydraulic drainage diversion system was constructed in 2008 to control contaminant sources by preventing ground water from rising into the pit waste and underlying contaminated bedrock. Also, a ground water extraction and treatment system was constructed in 2009-2010 to treat uranium, nitrate, perchlorate, and VOCs in ground water.

Natural attenuation has reduced tritium activities in ground water from a historic maximum of 2,660,000 pCi/L in 1998 to a first semester 2011 maximum of 575,000 pCi/L (April 2011) and has mitigated risk to onsite workers from inhalation of tritium vapors. Uranium activities have also decreased from a historic maximum of 781 pCi/L in 1998 to a first semester 2011 maximum of 172 pCi/L (April 2011). VOC concentrations are currently near or below cleanup standards. Nitrate concentrations in ground water remain relatively stable, while perchlorate concentrations have decreased.

1.5. Building 854 (OU 6)

TCE was released to soil and ground water through leaks and discharges of heat-exchange fluid, primarily between 1967 and 1984. Nitrate and perchlorate are also COCs in ground water. HE compounds, PCBs, dioxins, furans, tritium, and metals were identified as COCs in surface soil. No further action was selected as the remedy for metals, HMX, and tritium in surface soil.

In 1983, TCE-contaminated soil was excavated at the northeast corner of Building 854F. Ground water extraction and treatment has been conducted since 1999 to reduce VOC, nitrate, and perchlorate concentrations in ground water. PCB-, dioxin-, and furan-contaminated soil in the Building 855 former rinse water lagoon was excavated in 2005 (Holtzapple, 2005). The selected remedy for this OU includes monitoring, risk and hazard management, and ground water and soil vapor extraction and treatment. The interim remedial design was completed in 2003. Construction completion for the OU was achieved in September 2007. Three ground water extraction and treatment systems and one soil vapor extraction and treatment system currently operate in the OU.

Ground water remediation has reduced total VOC concentrations from a historic maximum of 2,900 µg/L in 1997 to a first semester 2011 maximum of 110 µg/L (April 2011). Nitrate concentrations have decreased from a historic maximum of 260 mg/L in 2003 to a first semester 2011 maximum of 50 mg/L (June 2011). Perchlorate concentrations in ground water have also decreased from 27 µg/L in 2003 to a first semester 2011 maximum of 15.9 µg/L (June 2011). Risks to onsite workers from inhalation of VOC vapors and from exposure to PCBs, dioxins, and furans in surface soil have been mitigated.

A Five-Year Review of remediation in the Building 854 OU was completed in January 2009 (Dibley et al., 2009a). The second Five-Year-Review is scheduled for 2014.

1.6. Building 832 Canyon (OU 7)

Contaminants were released from Buildings 830 and 832 through piping leaks and surface spills during past activities at these buildings. VOCs, nitrate, and perchlorate are the COCs in ground water. VOCs are the COCs in surface water at Spring 3. VOCs, nitrate, and HMX are the COCs in subsurface soil. HMX is also a COC in surface soil. No further action was selected as the remedy for HMX and nitrate in surface and subsurface soil.

Ground water and soil vapor extraction and treatment have been conducted since 1999 to reduce contamination in ground water and subsurface soil. The Building 832 Canyon OU remedy includes monitoring, risk and hazard management, MNA for nitrate, and ground water and soil vapor extraction and treatment. The interim remedial design was completed in 2006. Construction completion for the OU was achieved in September 2007. Three ground water extraction and treatment systems and two soil vapor extraction and treatment systems currently operate in this OU.

Remediation has reduced total VOC concentrations from a historical maximum of 13,000 µg/L in 2003 to a first semester 2011 maximum of 3,600 µg/L (April 2011). Perchlorate concentrations have been reduced from a historical maximum of 51 µg/L in 1998 to a first semester 2011 maximum of 14 µg/L (March 2011). Nitrate concentrations in ground water remain fairly stable, and are possibly the result of the ongoing contribution of nitrate from septic systems and natural bedrock sources. Nevertheless, natural denitrification processes continue to reduce nitrate concentrations to background levels near the site boundary. Remediation has also mitigated the risk to onsite workers in several locations in the Building 832 Canyon OU.

A Five-Year Review of remediation in the Building 832 Canyon OU was completed in August 2011 (Helmig et al., 2011). The second Five-Year-Review is scheduled for 2016.

1.7. OU 8

Operable Unit 8 includes the contaminant release sites that have a monitoring-only remedy: the Building 801 Dry Well and Pit 8 Landfill, Building 833, Building 845 and Pit 9 Landfill, the Building 851 Firing Table, and the Pit 2 Landfill. OU 8 release sites have a monitoring-only interim remedy because either: (1) contaminants in surface and subsurface soil/bedrock do not pose a risk to humans or plant and animal populations or a threat to ground water, (2) there is no ground water contamination, (3) contaminant concentrations in ground water do not exceed cleanup standards, and/or (4) the extent of contamination in ground water is limited. The first Five-Year Review for this OU is scheduled for 2013. These release sites are summarized below.

1.7.1. Building 801 Dry Well and the Pit 8 Landfill (OU 8)

The Building 801 Firing Table was used for explosives testing and operations resulting in contamination of adjacent soil with metals and uranium. Use of this firing table was discontinued in 1998, and the firing table gravel and some underlying soil were removed. Waste fluid was discharged to a dry well (sump) located adjacent to Building 801D from the late 1950s to 1984. The dry well was decommissioned and filled with concrete in 1984. VOCs, perchlorate and nitrate are COCs in ground water due to the past releases from the Building 801 Dry Well. VOC and nitrate concentrations in ground water are currently near or below cleanup standards or at background levels. Perchlorate is not currently detected in ground water. VOCs are COCs in subsurface soil, but do not pose a risk to human health. The adjacent Pit 8 Landfill received debris from the Building 801 Firing Table until 1974, when it was covered with compacted soil. There is no evidence of contaminant releases from the landfill.

The selected remedy for this area includes monitoring and risk and hazard management. No further action was selected as the remedy for VOCs in subsurface soil at Building 801.

No Remedial Design documents are required for this area.

1.7.2. Building 833 (OU 8)

TCE was used as a heat-exchange fluid in the Building 833 area from 1959 to 1982 and was released through spills and rinse water disposal, resulting in TCE-contamination of subsurface soil and shallow perched ground water. No contamination has been detected in the deeper regional aquifer. No COCs were identified surface soil at Building 833.

The selected remedy for Building 833 includes monitoring and risk and hazard management. No Remedial Design document is required for this area. Ground water monitoring at Building 833 has shown a decline in total VOC concentrations from a historic maximum of 2,100 µg/L in 1992 to a first semester 2011 maximum of 150 µg/L (February 2011).

1.7.3. Building 845 Firing Table and the Pit 9 Landfill (OU 8)

The Building 845 Firing Table was used from 1958 until 1963 to conduct explosives experiments. Leaching from firing table debris resulted in minor contamination of subsurface soil with depleted uranium and HMX but no unacceptable risk to human or ecological receptors or threat to ground water was identified. No contaminants have been detected in surface soil or in ground water at the Building 845 Firing Table. Debris generated at the Building 845 Firing Table was buried in the Pit 9 Landfill. There has been no evidence of contaminant releases from the Pit 9 Landfill.

The selected remedy for Building 845 and the Pit 9 Landfill includes monitoring and risk and hazard management. No further action was selected as the remedy for uranium and HMX in subsurface soil at Building 845. No Remedial Design documents are required for this area.

1.7.4. Building 851 Firing Table (OU 8)

The Building 851 Firing Table has been used for high-explosives research since 1962. VOCs and uranium-238 were identified as COCs in subsurface soil, and Research Department explosive (RDX), uranium-238, and metals as surface soil COCs. However, there is no risk to humans or animal populations, or threat to ground water associated with these contaminants in surface and subsurface soil. Uranium-238 was identified as a COC in ground water. However, it poses no risk to human or ecological receptors, and uranium activities are well below cleanup standards and within the range of background levels.

In 1988, the firing table gravel was removed and disposed in Pit 7. Gravel has been replaced periodically since then. The selected remedy for Building 851 includes monitoring and risk and hazard management. No further action was selected as the remedy for VOCs and uranium in surface and subsurface soil, and for RDX and metal in surface soil at Building 851. No Remedial Design document is required for this area.

1.7.5. Pit 2 Landfill (OU 8)

The Pit 2 Landfill was used from 1956 until 1960 to dispose of firing table debris from Buildings 801 and 802. Ground water data indicate a discharge of potable water to support a red-legged frog habitat located upgradient from the landfill may have leached depleted uranium from the buried waste. The frogs were relocated and the water discharge was discontinued, thereby removing the leaching mechanism. No contaminants were identified in surface or subsurface soil at the Pit 2 Landfill. No risk to human or ecological receptors has been identified at the Pit 2 Landfill.

The selected remedy for the Pit 2 Landfill includes monitoring and risk and hazard management. Monitoring data indicate that uranium activities remain below the cleanup standard. No Remedial Design document is required for this area.

1.8. Building 812 (OU 9)

The Building 812 Complex was built in the late 1950s-early 1960s and was used to conduct explosives tests and diagnostics until 2008. A Characterization Summary Report for this area was completed in 2005 (Ferry and Holtzapple, 2005). The Building 812 Complex was designated as OU 9 in March 2007 based on characterization results that indicated the presence of uranium, VOCs, HE compounds, nitrate, and perchlorate in environmental media. In 2008, a draft Remedial Investigation/Feasibility Study (RI/FS) describing the results of characterization activities and remedial alternatives for the Building 812 OU was submitted to the regulatory agencies. A DOE task force reviewed the soil-washing alternative and determined that it would not be effective at Site 300; therefore a soil-washing treatability study will not be performed. DOE is currently evaluating a new remedial strategy for contaminated soil at Building 812. Additional characterization began in 2011. A new RI/FS will be prepared following the completion of the characterization. A Proposed Plan will subsequently present the alternatives and a preferred remedy for public comment. A remedy will then be selected in an Amendment to the Site-Wide ROD.

1.9. Building 865/Advanced Test Accelerator

Building 865 facilities were used to conduct high-energy laser tests and diagnostics in support of national defense programs from 1980 to 1995. The Building 865 Complex housed a 275-foot linear electron accelerator called the Advanced Test Accelerator (ATA). The ATA was designed to produce a repetitively pulsed electron beam for charged particle beam research. In 2006, a Characterization Summary Report for this area was submitted to the regulatory agencies (Ferry and Holtzapple, 2006). Freon 113, Freon 11, and tetrachloroethene (PCE) were identified as COCs in ground water. However, concentrations of Freon 11 and 113 are well below their MCLs; and PCE is only detected in one well at a concentration above its MCL. The remediation pathway for Building 865 is currently being negotiated.

2. Site Chronology

The chronology of key HEPA OU environmental restoration events is summarized below.

1958–1989

- Surface spills at the drum storage and dispensing area for the former Building 815 steam plant resulted in TCE released to the ground surface until use of this area was discontinued in 1986.
- Waste fluids were discharged to dry well 810A from 1959 to 1985 resulting in release of VOCs to the subsurface.
- Wastewater containing HE compounds, nitrate, and perchlorate was discharged to former unlined rinsewater lagoons from the mid-to-late 1950s to 1985. Unlined HE rinsewater

lagoons were capped and closed between 1985 and 1989. Two double-lined surface impoundments were installed in 1984.

- TCE was detected in ground water collected in former onsite water-supply Well 6 in 1982. In 1989, Well 6 was destroyed and replaced with Well 20.

1990

- LLNL Site 300 was placed on the National Priorities List.

1992

- A Federal Facilities Agreement for Site 300 was signed.

1994

- The Site-Wide Remedial Investigation report for Site 300 was issued (Webster-Scholten et al., 1994).

1998

- The Building 815 Operable Unit Engineering Evaluation/Cost Analysis (Madrid and Jakub, 1998) proposed a Removal Action involving installation of ground water compliance monitoring wells and ground water extraction and treatment from onsite wells to prevent offsite migration of TCE.
- An Action Memorandum for the Building 815 Removal Action (Jakub, 1998) authorized an early phase of ground water cleanup as a Non Time-Critical Removal Action.
- Capping and closure of the HE Burn Pit was completed in 1998. These pits, located in the vicinity of Building 829, had been used to burn HE particulates and cuttings, explosive chemicals, and explosives-contaminated debris from the late 1950s until 1998.

1999

- The Site-Wide Feasibility Study for Site 300 was issued (Ferry et al., 1999).
- Ground water extraction and treatment was initiated in the distal portion of the Building 815 VOC plume near the site boundary to prevent offsite plume migration.

2000

- Ground water extraction and treatment was initiated in the Building 815 source area.

2001

- An Interim Site-Wide ROD for Site 300 was signed. The Interim Site-Wide ROD specified continued ground water and soil vapor extraction, administrative controls (e.g., risk and hazard management), monitoring, and no further action for: (1) VOCs in soil and bedrock at the HE rinsewater lagoons, and (2) VOCs and high melting explosive/research department explosive (HMX/RDX) in soil and bedrock at the HE Burn Pit, as the components of the selected interim remedy for the HEPA OU. The Interim Site-Wide ROD did not contain ground water cleanup standards. These standards were established in the 2008 Final Site-Wide ROD for Site 300.
- A Remedial Design Work Plan was issued that contained the strategic approach and schedule to implement the remedies in the Interim Site-Wide ROD (Ferry et al., 2001b).

2002

- The Interim Remedial Design Report for the HEPA OU was issued.

- The Compliance Monitoring Plan/Contingency Plan for the interim remedies was issued (Ferry et al., 2002b).
- Ground water extraction and treatment was initiated in the proximal portion of Building 815 plume.

2003

- Ground water extraction and treatment was initiated in the Building 817 source area.

2005

- Ground water extraction and treatment was initiated in the Building 829 source area.
- Ground water extraction and treatment was initiated in Building 817 proximal area.
- The HE surface impoundments south of Building 817 were closed.

2007

- The first HEPA OU Five-Year Review was issued.

2008

- The Site-Wide ROD with selected remedies and cleanup standards for Site 300 was signed. The remedy for the HEPA OU did not change between the 2002 and 2008 Site-Wide ROD, with the exception that ground water cleanup standards were added in the 2008 Site-Wide ROD.

2009

- The revised Compliance Monitoring Plan/Contingency Plan for the final remedies was issued (Dibley et al., 2009b).
- An Engineering Evaluation and Upgrade was initiated at 829-SRC Treatment Facility.

2010

- An Engineering Evaluation and Upgrade was initiated at 815-DSB Treatment Facility.
- An Explanation of Significant Difference (ESD) was submitted to change the treatment of nitrate at the Building 829-Source Treatment Facility (Ferry et al., 2010).

3. Background

3.1. Physical Characteristics

3.1.1. Site Description

LLNL Site 300 is a U.S. DOE experimental test facility operated by the Lawrence Livermore National Security (LLNS), Limited Liability Corporation. It is located in the Eastern Altamont Hills 17 miles east of Livermore, California (Figure 1). At Site 300, DOE conducts research development, and testing associated with high-explosive materials. Historic Site 300 operations involved the release of a number of contaminants to the environment. These releases occurred primarily from spills, leaking pipes, leaching from unlined landfills and pits, high explosive test detonations, and disposal of waste fluids in lagoons and dry wells (sumps). The climate at Site 300 is semi-arid; approximately 10 to 15 inches of precipitation falls each year, mostly in the winter.

The HEPA OU is approximately 934 acres in size, and is located in the southeastern part of Site 300 (Figure 2). This area is characterized by steep, hilly terrain with northwest-southeast trending canyons and ridges. Facilities in the HEPA have been in use since the late 1950s for the chemical formulation, mechanical pressing, and machining of HE compounds into shaped detonation devices. Solid HE waste remaining after machining operations was incinerated at the HE Burn Pit located near Building 829 in the northern part of the HEPA OU. Liquid waste generated during machining operations was discharged to former unlined disposal lagoons.

In 1984, two double-lined HE surface impoundments were installed south of Building 817 to receive all HE process waste water and replace the unlined disposal lagoons. The surface impoundments allowed dissolved explosives chemicals in the wastewater to degrade from exposure to ultraviolet rays in sunlight. These surface impoundments were closed in 2005 under the oversight of the California Regional Water Quality Control Board (RWQCB).

In 1997, the Final Closure Plan for the HE Burn Pit facility at Building 829 was submitted to the regulatory agencies (Lamarre et al., 1997). This facility consisted of three unlined pits and an open-air burn unit to incinerate HE waste. As specified in the Final Closure Plan, the HE Burn Pit facility was dismantled, capped, and three deep ground water wells were installed in the regional $Tnbs_1$ aquifer for post-closure monitoring.

Twelve confirmed chemical release sites (source areas) have been identified in the HEPA OU. A former drum rack that was used to store and dispense TCE near Building 815 is considered to be the primary source of VOCs. The former unlined HE rinsewater disposal lagoons at Buildings 806, 807, and 817 and the dry well at Building 810 are considered the primary source areas of HE compounds and perchlorate. There are multiple natural and anthropogenic sources of nitrate in the ground water. Studies suggest that natural soil and septic discharges are probably a greater source of nitrate than discharge of HE-bearing waste fluids to the former lagoons and dry wells (Madrid et al., 2006).

Six ground water extraction and treatment systems are currently in place and operating to remediate VOCs, nitrate, perchlorate, and HE compounds. To evaluate the progress of remediation, ground water is monitored for these constituents in all monitor, extraction and guard wells. The locations of existing monitor, extraction and water supply wells and treatment facilities are shown on Figure 3.

3.1.2. Hydrogeologic Setting

This section describes the general hydrogeologic setting for the HEPA OU, including the unsaturated zone and the six hydrostratigraphic units (HSUs) underlying the area. A conceptual hydrostratigraphic column for the southeast corner portion of Site 300 including the HEPA is shown on Figure 4. Hydrogeologic cross-sections showing the HSUs and the vertical distribution of total VOCs, RDX and perchlorate in the HEPA OU are shown on Figures 5, 6, and 7 respectively.

3.1.2.1. Vadose (Unsaturated) Zone

The thickness of the vadose zone in the HEPA varies from less than 20 feet (ft) in the Quaternary alluvial sand and gravel (Qal) of the Corral Hollow Creek floodplain to over 350 ft at the higher topographic elevations in the northwestern part of the OU. In some parts of the HEPA, limited amounts of perched ground water occur in the Tertiary Pliocene nonmarine

sediments (Tpsg-Tps) and Tertiary Neroly Upper Siltstone/Claystone ($Tnsc_2$) stratigraphic units within the vadose zone.

3.1.2.2. Saturated Zone

The six HSUs in the HEPA OU are described below.

Qal HSU – The Qal HSU consists of alluvial sands and gravels along with minor silts and clays located along the southern Site 300 border within the floodplain of Corral Hollow Creek. It ranges up to 35 ft in total thickness, but saturated thickness is spatially and temporally variable depending on seasonal rainfall. Ground water in this HSU flows generally to the east. The Qal HSU is recharged by surface runoff from nearby canyons, by direct infiltration during seasonal rainfall events, and from confined ground water in bedrock aquifers that subcrop beneath the Qal. Corral Hollow Creek discharges to the east into the San Joaquin Valley.

Tpsg-Tps HSU – The Tertiary Pliocene sand and gravel (Tpsg-Tps) HSU consists of variably saturated, perched ground water present in Tertiary sand and gravels (Tpgs) and the underlying Tps claystones. Perched ground water is present at depths ranging from ground surface where it discharges at Spring 4 to 45 ft below ground surface (bgs) in the vicinity of Building 815. Ground water in this HSU flows to the southeast.

$Tnbs_2$ HSU – The Tertiary Neroly Upper Blue Sandstone ($Tnbs_2$) HSU is saturated beneath the southern part of the HEPA OU from Building 815 to the site boundary. Ground water in the $Tnbs_2$ HSU occurs under unconfined to confined (including flowing artesian) conditions. Under unstressed conditions, $Tnbs_2$ ground water levels in the southern part of the HEPA are higher than water levels in the overlying Qal HSU, resulting in an upward hydraulic gradient. However, under stressed (pumping) conditions, this upward hydraulic gradient can be reversed if the potentiometric head elevation in the $Tnbs_2$ HSU falls below that in the Qal HSU. Under these conditions, ground water from the Qal HSU flows downward into the $Tnbs_2$ HSU. The saturated thickness of the $Tnbs_2$ HSU ranges from 0 to 60 ft. Depth to ground water in the $Tnbs_2$ HSU ranges from 40 to 165 ft bgs. Ground water in this HSU flows to the southeast.

$Tnsc_{1b}$ HSU – Ground water occurs under unconfined to confined conditions in the Tertiary Neroly Lower Siltstone/Claystone ($Tnsc_{1b}$) HSU beneath the HEPA OU. The $Tnsc_{1b}$ HSU is saturated beneath the southern part of the HEPA with a saturated thickness of approximately 25 ft. Depth to ground water in this HSU ranges from 145 to 250 ft bgs. Ground water flow is to the southeast.

$Tnbs_1$ HSUs – The Tertiary Neroly Lower Blue Sandstone ($Tnbs_1$) HSU consists of Neroly Formation sandstone and conglomerate interbedded with siltstone and claystone. These HSUs are present throughout the HEPA OU. Two water-bearing zones are present in the $Tnbs_1$ stratigraphic unit which are separated by a 10-ft thick claystone (claystone marker bed) that exists throughout the southeast corner of Site 300. Ground water occurs under unconfined to confined (including flowing artesian conditions) in the upper and lower $Tnbs_1$ HSUs. The saturated thickness of the upper $Tnbs_1$ HSU ranges from 75 to 125 ft with depths to ground water ranging from 300 to 400 ft bgs. The saturated thickness of the lower $Tnbs_1$ HSU is greater than 150 ft with depths to ground water ranging from 400 to 500 ft bgs. Ground water flow is to the southeast.

The lower $Tnbs_1$ HSU is the currently the main water-supply aquifer for Site 300; however, the site will eventually be transitioning to the Hetch-Hetchy water supply. Site 300's water

needs are currently supplied by onsite water-supply Well 20, which is located in the southern part of the HEPA OU and is completed in the lower $Tnbs_1$ HSU. Onsite water-supply Well 18 is located in the same area and serves as a backup water supply. After the transition to Hetch-Hetchy water occurs, Well 20 will serve as a backup water supply well and Well 18 will no longer be used.

3.2. Land and Resource Use

Before DOE established Site 300 as a remote testing facility in 1955, the area was used for cattle grazing. Site 300 is currently an operating facility, and will remain under DOE control for the reasonably anticipated future. Less than five percent of Site 300's 7,000 acres is developed. There have been no changes in land, building, or ground water use in the HEPA OU since the Site-Wide ROD was signed in 2008 and, other than the changes in onsite water supply uses documented below, none are anticipated.

The HEPA is still used for machining and storage of HE and is accessible only to DOE/LLNL workers.

The HEPA OU extends to the southeastern site boundary. The land adjacent to the OU consists of private rangeland. The nearest major population center (Tracy, California) is 8.5 miles to the northeast. There is no known planned modification or proposed development of the offsite rangeland adjacent to the OU.

At Site 300, ground water is used for a variety of onsite water supply needs including cooling towers, HE processing, dust control and fire suppression. Bottled water is the primary source of onsite drinking water, but potable ground water from onsite water-supply Well 20 is also available. Onsite water-supply Well 20 is completed in the Lower $Tnbs_1$ bedrock HSU at a depth of 387 to 518 ft bgs. Although several nearby ground water monitor wells that are completed in the shallower $Tnbs_2$ HSU contain TCE, TCE has not been detected in Well 20 because it is sealed through the shallow aquifer. Well 18, also located in the southeast part of the HEPA OU, is no longer used as a water supply well due to sporadic detections of TCE in samples collected from this well. Although Well 18 is inactive, it is considered a backup water supply well for emergency fire suppression. As mentioned in Section 3.1.2.2, Site 300 plans to transition to the Hetch-Hetchy water supply in 2012. After this transition occurs, Well 20 will be used as a backup water supply and Well 18 will no longer be used. The lower pumping rates at Well 20 are not expected to impact groundwater flow and contaminant transport in the $Tnbs_2$ HSU because Well 20 is not completed in this interval. However, there is an offsite water supply well (GALLO1) located near the site boundary of HEPA and intermittent pumping from this well may influence ground water levels in the $Tnbs_2$ HSU. Surface water at Site 300 is not consumed by humans. In the past, former onsite water supply Well 6 was also used at Site 300; however, TCE was detected in this well in 1982 and in 1989, the well was abandoned and replaced with Well 20.

Site 300 has unique environmental qualities, largely because it has not been grazed for over 50 years and contains several habitat types and numerous special status species (e.g., threatened and endangered species, migratory birds, and rare plants). Annual grasslands cover the majority of the HEPA OU, with an isolated patch of blue oak woodland that crosses the southwest boundary of the OU. A wetland associated with Spring 14 also occurs in this area. Spring 5, an area of shallow ground water centrally located within the OU, does not have significant wetland

development, as surface water is absent from this location. Special status species found within the HEPA OU include the Big Tarplant (*Blepharizonia plumosa*), an extremely rare late-season flowering plant included on the California Native Plant Society's List 1B. The entire OU resides within the upland habitat for the threatened California tiger salamander (*Ambystoma californiense*). The wetland associated with Spring 14 provides breeding habitat for the threatened California red-legged frog (*Rana aurora draytonii*), and the entire OU resides within the upland dispersal habitat for this species. Loggerhead shrikes (*Lanius ludovicianus*), a California Species of Special Concern, have been observed in the HEPA OU, and nesting has also been observed within the OU. A five-year ecological review included in the 2008 Annual Compliance Monitoring Report updated the assessment of the ecological impacts from Site 300 contaminants, and found no impact to ecological receptors from releases within the HEPA OU beyond those originally identified in the baseline ecological risk assessment (see Section 7.5.2), although chloride in Spring 14 was identified as requiring future review. An LLNL ecologist reviewed ecological data collected between 2008 and 2011 for the HEPA area to evaluate whether any changes in contaminant or ecological conditions that could impact ecological receptors. No changes were identified. Access to these unique animal and plant populations is controlled and interactions with the wildlife are avoided.

3.3. History of Contamination

Surface spills at the drum storage and dispensing area for the former Building 815 steam plant, where TCE was used to clean pipelines, resulted in the release of TCE to the ground surface. This release site is the main source of TCE in ground water in the HEPA OU. Another minor source of TCE in ground water resulted from leaking contaminated waste stored at the former Building 829 Waste Accumulation Area. In addition, between 1959 and 1985, waste fluids were discharged to dry well 810A, resulting in the release of VOCs to the subsurface. From the mid-to-late 1950s to 1985, rinsewater containing HE compounds was discharged to nine former unlined rinsewater lagoons. The largest volumes of HE-bearing rinsewater were discharged from Buildings 806, 807, and 817 (Henry, 1981; Crow et al., 1986) to the former rinsewater lagoons. These former rinsewater lagoons are the primary source of HE compounds (mainly RDX) and perchlorate in ground water. Three Resource Conservation and Recovery Act (RCRA)-regulated HE Burn Pit was located in the vicinity of Building 829 in which HE particulates and cuttings, explosive chemicals, and explosives-contaminated debris were burned. Reportedly, nearly 150 kilograms (kg) per month of explosives, reactive chemicals, and explosives-contaminated combustible waste were destroyed in the burn pit. The facility operated from the late 1950s until 1998 when the HE Burn Pit was capped and closed under RCRA. No significant HE Burn Pit contamination has been detected in environmental media.

3.4. Initial Response

DOE/LLNL began environmental investigations in the HEPA OU in the early 1980s to evaluate the sources of contamination detected in former water-supply Well 6 and to determine if wastewater discharges into the unlined disposal lagoons had contaminated ground water. Since then, 194 boreholes have been drilled in the HEPA OU; 95 of these boreholes have been completed as ground water monitoring, injection or extraction wells (Figure 3). The geologic and chemical data from these wells and boreholes were used to characterize the site hydrogeology and to monitor temporal and spatial changes in saturation and dissolved

contaminants. Site characterization activities also included analyses of water samples from springs, and passive and active soil vapor surveys.

As summarized in Section 2, remediation activities at the HEPA OU conducted prior to the 2001 Interim Site-Wide ROD included sealing and abandoning former water-supply Well 6, decommissioning of the former rinsewater lagoons and dry wells, closure and capping of the former HE Burn Pit, and extraction and treatment of contaminated ground water.

3.5. Contaminants of Concern

Four types of COCs have been identified in environmental media in the HEPA OU: VOCs, HE compounds, perchlorate, and nitrate. VOCs have been identified as COCs in subsurface soil, ground water, and surface water at Spring 5 (Section 3.5.1). The HE compounds HMX and RDX are COCs in surface soil and subsurface soil/rock, and RDX and 4-Amino-2,6-dinitrotoluene (4-ADNT) are COCs in ground water (Section 3.5.2). Perchlorate and nitrate are COCs only in ground water (Sections 3.5.3 and 3.5.4, respectively). The distribution of COCs in ground water HSUs in the HEPA OU is discussed in Section 3.5.5.

3.5.1. VOCs in Subsurface Soil, Ground Water, and Surface Water

VOCs, primarily TCE, a human carcinogen, are present in subsurface soil and rock, in surface water at Spring 5, and in ground water. The baseline human health risk assessment estimated an excess cancer risk of 5×10^{-6} to onsite workers inhaling VOCs evaporating from subsurface soil into outdoor ambient air in the vicinity of Building 815.

TCE is a COC in HEPA OU ground water and is present at concentrations above the 5 μg/L MCL cleanup standard. While chloroform, 1,1-DCE, cis-1,2-DCE were identified as ground water COCs, their current concentrations are below their respective MCL cleanup standards.

An excess cancer risk of 1×10^{-5} was also estimated for onsite workers inhaling TCE and 1,1-dichloroethylene (DCE) volatilizing from surface water at Spring 5.

Risk mitigation remediation progress is discussed in Section 7.5.2.

The baseline ecological assessment determined that a risk from copper and cadmium existed for aquatic organisms, ground squirrels, and deer. Aquatic organisms are at risk from copper in the shallow, near-surface ground water at Spring 5. The Toxicity Quotient using California Applied Action Levels exceeded 1 for copper in ground water samples from this location. Individual adult ground squirrels and individual adult and juvenile deer are at risk from ingestion of cadmium in surface soil. The combined oral and inhalation pathway Hazard Quotient exceed 1 for these species, which was driven by the oral pathway. Surveys for the presence of surface water at Spring 5, and algae and micro-invertebrate bioassays conducted to identify the true risk to aquatic organisms found no current adverse impact. Similarly, site-wide population surveys to identify the current risk to deer and ground squirrels found no adverse impacts.

3.5.2. HE Compounds in Surface Soil, Subsurface Soil/Rock, and Ground Water

The HE compounds HMX and RDX are human carcinogens present in surface soil, subsurface soil and rock, and ground water in the HEPA OU. The baseline human health risk assessment calculated an excess cancer risk of 2×10^{-6} for RDX assuming human ingestion of contaminated ground water from a hypothetical well located at the Site 300 boundary. RDX is a COC in HEPA OU ground water and is present at concentrations above the 1 μg/L reporting

limit cleanup standard. There was no risk to onsite workers associated with HMX and RDX in surface and subsurface soil under an industrial land use scenario. There is no risk to offsite residents because this soil contamination is wholly contained onsite and there are no pathways through which offsite residents could be exposed. Other HE compounds have also been sporadically detected in ground water in the HEPA OU near the Building 815-Source and Building 817-Source treatment facilities, including nitrobenzene and 4-ADNT. Detections of HE compounds other than HMX and RDX reflect a recent change in the Site 300 sampling plan requested analyses to EPA Method 8330. Previously, only RDX and HMX were analyzed and reported, however, now the full EPA Method 8330 suite of compounds is being analyzed and reported. These compounds are discussed in Section 6.4.1.2.3.

3.5.3. Perchlorate in Ground Water

Perchlorate, while not a carcinogen, interferes with iodide uptake into the thyroid gland. Because iodide is an essential component of thyroid hormones, perchlorate may disrupt thyroid functions by decreasing hormone production (U.S. EPA, 2005). There was no human health risk or hazard identified associated with perchlorate in ground water because there is no exposure pathway. However, perchlorate is a COC in HEPA OU ground water and is present at concentrations above the 6 μg/L California State MCL cleanup standard.

3.5.4. Nitrate in Ground Water

Elevated nitrate is present in ground water as a result of releases from a combination of natural and anthropogenic sources in the HEPA OU. In addition to natural soil nitrate and septic system discharges, HE- and nitrate-bearing wastewater was discharged to the former lagoons and dry wells in the HEPA OU. Nitrate can cause non-carcinogenic health effects if ingested at elevated concentrations. There was no human health risk or hazard identified associated with nitrate in ground water. However, nitrate is a COC in HEPA OU ground water and is present at concentrations above the 45 mg/L MCL cleanup standard.

3.5.5. Distribution of COCs in Ground Water HSUs

Total VOCs, RDX, perchlorate, and elevated nitrate are the main focus of ground water remediation in the HEPA OU and most ground water contamination occurs in the $Tnbs_2$ HSU. The $Tnbs_2$ HSU was the main water-supply aquifer for Site 300 before contaminants were detected in it during the mid-1980s. The current Site 300 water-supply well (Well 20) pumps from the deeper and uncontaminated lower $Tnbs_1$ HSU. In the future, Site 300 will be transitioning to the Hetch-Hetchy reservoir as its primary water supply. Local ranchers continue to pump water from offsite wells completed in the $Tnbs_2$ HSU for domestic use and livestock watering. Guard wells and offsite water-supply wells are monitored regularly for HEPA COCs.

In the $Tnsc_{1b}$ HSU, ground water contamination has not been detected in most areas. Only a limited volume of perched ground water is contaminated with TCE, perchlorate, and elevated nitrate in the HEPA OU. This perched water is located beneath the former Building 829 HE Burn Pit and Waste Accumulation Area in the northwest part of the HEPA OU. The $Tnsc_{1b}$ HSU also contains contaminants from sources located in the Building 832 Canyon OU upgradient (northeast) of the HEPA OU. The Building 832 Canyon OU is most likely the source of $Tnbs_2$ HSU contamination located near the W-830-2216 extraction well.

Total VOCs, RDX, perchlorate, and elevated nitrate have also been detected in the sands and gravels of the Tpsg-Tps HSU in the vicinity of Building 815, although wells in this area have recently been dry. Elevated nitrate, perchlorate and total VOCs are also present in the Tpsg-Tps HSU near the Building 817 Proximal treatment facility. No contamination has been detected in the Tps portion of the Tpsg-Tps HSU, or in the upper and lower $Tnbs_1$ HSUs in the HEPA OU.

3.6. Summary of Basis for Taking Action

Remedial actions were initiated in the HEPA OU to address unacceptable human health risks associated with onsite worker inhalation exposure to VOCs volatilizing from the subsurface soil to outdoor air in the vicinity of Building 815 and surface water at Spring 5. VOCs, perchlorate, and nitrate are present in HEPA ground water at concentrations exceeding MCL cleanup standards, and RDX is present in ground water at concentrations exceeding its cleanup standard.

4. Remedial Actions

4.1. Remedy Selection

The remedy selected for the HEPA OU is intended to achieve the following Remedial Action Objectives (RAOs):

For Human Health Protection:

- Restore ground water containing contaminant concentrations above cleanup standards.
- Prevent human ingestion of ground water containing contaminant concentrations (single carcinogen) above cleanup standards.
- Prevent human inhalation of VOCs volatilizing from subsurface soil to air that pose an excess cancer risk greater than 10^{-6} or hazard index greater than 1, a cumulative excess cancer risk (all carcinogens) in excess of 10^{-4}, or a cumulative hazard index (all noncarcinogens) greater than 1.
- Prevent human exposure to contaminants in media of concern that pose a cumulative excess cancer risk (all carcinogens) greater than 10^{-4} and/or a cumulative hazard index greater than one (all noncarcinogens).

For Environmental Protection:

- Restore water quality to ground water cleanup standards within a reasonable timeframe and to prevent plume migration to the extent technically and economically practicable. Maintain existing water quality that complies with ground water cleanup standards to the extent technically and economically practicable. This will apply to both individual and multiple constituents that have additive toxicology or carcinogenic effects.
- Ensure ecological receptors important at the individual level of ecological organization (listed threatened or endangered, State of California species of special concern) do not reside in areas where relevant hazard indices exceed 1.
- Ensure existing contaminant conditions do not change so as to threaten wildlife populations and vegetation communities.

In the 2001 Interim Site-Wide ROD, the remedy for the HEPA OU was selected based on its ability to contain contaminant sources, prevent further plume migration, remove contaminant mass from the subsurface, and protect human health and the environment. The interim remedy was selected as the final remedy in the 2008 ROD.

The selected remedy for the HEPA OU consisted of:

1. Ground water monitoring to evaluate the effectiveness of the remedial action, to determine when cleanup standards are met, and to ensure there is no impact to downgradient water-supply wells.
2. Risk and hazard management to prevent onsite worker exposure to VOCs volatilizing from Spring 5 until risk and hazard is mitigated through active remediation. Institutional/land use controls will be implemented to prevent human exposure to contamination and to protect the integrity of the remedy.
3. Extracting and treating VOCs, HE compounds, and perchlorate in ground water to mitigate unacceptable VOC inhalation risk for onsite workers, prevent further impacts to ground water and offsite plume migration, and reduce contaminant concentrations in ground water to cleanup standards.
4. MNA of nitrate in ground water.

4.2. Remedy Implementation

Ground water extraction and treatment systems (GWTS) have been operating in the HEPA OU since 1999. The location of ground water extraction wells and treatment facilities are shown in Figure 3. There are six GWTSs currently operating in the OU:

1. Building 815-Source (815-SRC),
2. Building 815-Proximal (815-PRX),
3. Building 815-Distal Site Boundary (815-DSB),
4. Building 817-Source (817-SRC),
5. Building 817-Proximal (817-PRX), and
6. Building 829-Source (829-SRC).

Since the last HEPA Five-Year Review, formal engineering evaluations and upgrades were conducted at treatment facilities 829-SRC and 815-DSB. This activity includes: (1) a comprehensive assessment and testing of the existing ground water extraction wellfield and treatment system to determine its effectiveness in reducing contaminant concentrations, mass, and plume size, and (2) identifying, designing, and implementing extraction wellfield and/or treatment facility upgrades to ensure reliable and efficient operations and accelerate site cleanup and completion (i.e., replacing aging system components, increasing facility capacity to accommodate flow from additional extraction wells). The treatment facility changes associated with these engineering evaluations and upgrades are discussed in this section.

The 815-SRC GWTS began operation in September 2000, removing VOCs (primarily TCE), HE compounds (RDX and HMX), and perchlorate from ground water. Initially, the system extracted from one extraction well (W-815-02) and consisted of aqueous-phase granular activated carbon (GAC), an ion-exchange system, and an anaerobic bioreactor for nitrate destruction. The treated effluent was discharged to a misting system. The anaerobic bioreactor

was decommissioned in 2003. In 2005, the wellfield was expanded to include extraction well W-815-04, with a current combined flow rate of approximately 1.2 gallons per minute (gpm). The current GWTS configuration includes a Cuno filter to remove particulates, two ion-exchange resin columns connected in series for perchlorate removal, and three aqueous-phase GAC canisters (also connected in series) for VOC and HE compound removal. In 2005, the discharge method of misting was replaced by injection of the treated effluent into well W-815-1918 for *in situ* denitrification in the $Tnbs_2$ HSU.

The 815-PRX GWTS began operation in October 2002, removing TCE and perchlorate from ground water. Ground water is extracted from wells W-818-08 and W-818-09 at a current combined flow rate of approximately 2.25 gpm. To increase hydraulic capture in this area, the combined flow rates for these extraction wells were increased by approximately 0.5 gpm beginning in 2010. The current GWTS configuration includes a Cuno filter to remove particulates, two ion-exchange resin columns connected in series for perchlorate removal, and three aqueous-phase GAC canisters (also connected in series) for TCE removal. In 2005, the discharge method of misting was replaced by injection of the treated effluent into well W-815-2134 where *in situ* natural denitrification converts nitrate to nitrogen in the $Tnbs_2$ HSU.

The 815-DSB GWTS began operation in September 1999 removing low concentrations (less than 10 µg/L) of TCE from ground water extracted near the Site 300 boundary. Ground water is currently extracted from wells W-35C-04 and W-6ER at a combined flow rate of approximately 3 to 4 gpm. During the review period, an engineering evaluation and upgrade was conducted at the 815-DSB GWTS. Facility upgrades included replacing aging system components (i.e., control system, electronics, and pipelines) and increasing its capacity to accommodate flow from additional extraction wells by installing new treatment media vessels and media. As part of this upgrade, monitor wells W-815-2111, W-815-2110, W-6K and W-6L and all extraction wells were be outfitted with pressure transducers and added to the treatment facility real-time monitoring system (TFRT). The TFRT system allows ground water elevations to be monitored remotely in real-time via a computer network and is especially useful for monitoring water level changes during hydraulic tests and other stressed conditions. The 815-DSB GWTS originally operated intermittently on solar-power until site power was installed in 2005 which allowed the system to operate 24-hour/day. The current GWTS configuration includes a Cuno filter to remove particulates and three aqueous-phase GAC canisters connected in series for TCE removal. The treated effluent is discharged to an infiltration trench.

The 817-SRC GWTS began operation in September 2003, removing HE compounds (RDX and HMX) and perchlorate from ground water. Well W-817-01 extracts ground water from a very low yield portion of the $Tnbs_2$ aquifer. It pumps ground water intermittently using solar power at current flow rates ranging from 40 to 160 gallons per month. The current GWTS configuration includes a Cuno filter to remove particulates, two ion-exchange resin columns connected in series for perchlorate removal, and three aqueous-phase GAC canisters (also connected in series) for HE compound removal. Treated ground water is injected into upgradient injection well W-817-06A where *in situ* natural denitrification converts nitrate to nitrogen in the $Tnbs_2$ HSU.

The 817-PRX GWTS began operation in September 2005, removing VOCs, RDX, and perchlorate from ground water. Initially, ground water was extracted from wells W-817-03 and W-817-04 at a combined flow rate of approximately 1.0 gpm, although the vast majority of ground water was extracted from well W-817-03. Due to the low yield from ground water

extraction well W-817-04, extraction from this well was discontinued in December 2007. In 2007, the extraction wellfield was also expanded to include Tpsg-Tps HSU extraction well, W-817-2318. Ground water is currently extracted from both wells at a combined flow rate of approximately 1.5 to 2.0 gpm. At 817-PRX, the current GWTS configuration includes a Cuno filter to remove particulates, two aqueous-phase GAC canisters connected in series for TCE and RDX removal, and three ion-exchange resin columns (also connected in series) for perchlorate removal. A third aqueous-phase GAC canister completes the treatment chain, and is placed in this position to remove any residual organic compounds that may be emitted from new ion-exchange resin. Treated ground water containing nitrate is injected into upgradient injection wells W-817-2109 and W-817-02 that was added in 2007. The treated effluent is split between the two injection wells where an *in situ* denitrification process reduces the nitrate to nitrogen in the $Tnbs_2$ HSU.

The 829-SRC GWTS began operation in August 2005, removing VOCs, nitrate, and perchlorate from ground water. The GWTS configuration included two ion-exchange resin columns connected in series for perchlorate removal, three aqueous-phase GAC canisters (also connected in series) for VOC removal, and a biotreatment unit to treat nitrate. An Explanation of Significant Difference (ESD) was approved by the regulatory agencies in 2010. The ESD documented the decision to use ion-exchange treatment media to remove nitrate from ground water, rather than the existing biotreatment unit (BTU) because:

1. The ion-exchange columns are effectively removing the nitrate to meet effluent discharge limits, rendering the BTU unnecessary,
2. The BTU is impractical under the operational conditions at B829-SRC.
3. Elimination of the BTU is expected to increase the overall operational efficiency of the 829-SRC treatment facility, and decrease operation and long-term maintenance efforts.

In 2010-2011, an engineering evaluation and upgrade was conducted at the 829-SRC treatment facility. As part of this upgrade, the treatment train was modified per the ESD to remove the biotreatment unit for the removal of nitrate. Solar power continues to be used to extract ground water from well W-829-06 at a flow rate of approximately 1 to 10 gallons per day (gpd). The current configuration includes two ion-exchange resin columns connected in series for perchlorate and nitrate removal and three aqueous-phase GAC canisters (also connected in series) for VOC removal. Treated effluent is injected into upgradient well W-829-08.

4.3. System Operations/Operation and Maintenance

The HEPA OU ground water extraction and treatment systems are operating as designed and no significant operations, performance, maintenance, or cost issues were identified during this review. All required documentation is in place, and treatment system operations and maintenance (O&M) activities are consistent with established procedures and protocols.

O&M procedures are contained in the following documents:

- Health and Safety Plan and Quality Assurance/Quality Control Plan for the O&M of the HEPA Treatment Facilities, contained within the Interim Remedial Design document.
- Operations and Maintenance Manual for Miniature Treatment Units, Ground Water Treatment Units, and Solar Treatment Units, Volume 13 (Martins, 2007).

- Operations and Maintenance Manual, Volume 1: Treatment Facility Quality Assurance and Documentation (LLNL, 2004).
- Integration Work Sheet Safety Procedure #11341: Ground Water and Soil Vapor Treatment Facility Operations at Site 300.
- Integration Work Sheet Safety Procedure #11314: Environmental Restoration Department (ERD) Site 300 Ion Exchange Resin Emplacement.
- Integration Work Sheet Safety Procedure #11313: ERD Site 300 Off-Road Driving Training.
- Integration Work Sheet Safety Procedure #11343: ERD Routine Ground Water Sampling & Water Level Monitoring at Site 300.
- Integration Work Sheet Safety Procedure #14984: ERD Routine Electronic Operations at Site 300.
- Integration Work Sheet Safety Procedure #11339: ERD Site 300 Hydraulic Pump Operation.
- Integration Work Sheet Safety Procedure #11346: Spent Aqueous and Vapor-phase Granular Activated Carbon (GAC) Replacement at Site 300.
- LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (Goodrich and Lorega, 2009).
- HEPA Substantive Requirements and the Monitoring and Reporting Program issued by the California RWQCB.
- Site-Wide Compliance Monitoring Plan/Contingency Plan for Interim Remedies at LLNL Site 300 until superseded by Site-Wide Compliance Monitoring Plan/Contingency Plan for Remedies at LLNL Site 300.

Monitoring and optimizing the performance and efficiency of the extraction and treatment systems comprises a large portion of the O&M activities. Extracted ground water is sampled throughout the treatment process to ensure compliance with discharge requirements. Treatment system parameters such as pressure and flow are routinely recorded to anticipate potential mechanical problems and monitor system performance.

The major O&M activities for the HEPA ground water and soil vapor treatment systems include:

- Maintaining the particulate filters.
- Maintaining the injection wells and infiltration trenches used to discharge treated ground water.
- Protecting the units from freezing in cold weather.
- Replacing and properly disposing of spent GAC and resin.
- Routinely inspecting and maintaining extraction well pumps, pipelines, and flow meters.

The treatment systems have consistently operated in compliance with all regulatory requirements.

The budgeted and actual environmental restoration costs for the HEPA OU are tracked closely and are consistently within or near the allocated budget. Table 1 presents the actual costs for the last five fiscal years, 2007 through 2011.

4.4 Institutional Controls

Institutional/land use controls are non-engineered actions or measures used to prevent or limit the potential for human exposure to contamination at the HEPA OU and to protect the integrity of the remedy. The general types of institutional/land use controls that are used to prevent human exposure to contamination at the HEPA OU include:

- Access controls – Measures such as fences, signs, and security forces that are used to prevent exposure by controlling and/or restricting access to areas of contamination.
- Administrative controls – Measures such as pre-construction review and controls for limiting or restricting access to contaminated areas and prohibitions on water supply well drilling.
- Land use controls – Includes prohibitions on transferring land with unmitigated contamination that could cause potential harm under residential or unrestricted land use.

Table 2 presents a description of: (1) the institutional/land use control objective and duration, (2) the risk necessitating land use controls, and (3) the specific institutional/land use controls and implementation mechanisms used to prevent exposure to contamination at the HEPA OU. Figure 8 shows the specific areas of the HEPA OU where the institutional/land use controls will be implemented and maintained.

Monitoring and inspection of the HEPA OU will be performed throughout the remediation period to determine whether the institutional/land use controls remain protective and consistent with all remedial action objectives. In addition, DOE will review facility and land use to evaluate changes in exposure pathway conditions that could affect the risk assessment assumptions and calculations.

The 2011 institutional controls inspection found all institutional controls were in place and properly implemented. The checklist was presented in the 2011 Annual Compliance Monitoring Report.

Institutional/land use controls are included in the Risk and Hazard Management Program contained in the Site-Wide Compliance Monitoring Plan. Any new or modified institutional/land use controls resulting from the Five-Year Review process will be incorporated in the Risk and Hazard Management Program contained in the revised Site-Wide Compliance Monitoring Plan. Risk and hazard monitoring results conducted during the year are submitted to the U.S. EPA and State regulatory agencies in the Annual Site 300 Site-Wide Compliance Monitoring Reports.

The land use controls and requirements described herein are only applicable to the HEPA OU and associated contaminated environmental media that are being addressed through the CERCLA process. DOE will implement, maintain, and enforce these institutional/land use controls at the HEPA OU for as long as necessary to keep the selected remedy protective of human health and the environment.

As documented in the Site-Wide ROD, if DOE later transfers these procedural responsibilities to another party by contract, property transfer agreement, or through another means, DOE will retain ultimate responsibility for the integrity of the remedy. In the event that

the property is transferred in the future, DOE will execute a land use covenant at the time of transfer in compliance with California Code of Regulations Title 22, Division 4.5, Chapter 39, Section 67391.1. If the Site 300 property were to be transferred to an entity outside the U.S. DOE, the necessary institutional/land use controls would be determined prior to the property transfer based on: (1) the intended land use subsequent to the property transfer, and (2) contamination and associated risk, if any, remaining at the HEPA OU. DOE distributed a Memorandum to the Administrative File on March 13, 2007 documenting this agreement.

The institutional controls were reviewed and are still effective for preventing exposure to contaminated media. Therefore, no changes to the Risk and Hazard Management Program contained in the revised Site-Wide Compliance Monitoring Plan are required.

5. Progress Since Last Review

This section describes the Protectiveness Statement and recommendations and follow-up actions from the 2007 HEPA OU Five-Year Review. It also describes the status of the actions recommended in this previous review.

5.1. Protectiveness Statement from Last Review

The 2007 HEPA OU Five-Year Review indicated that the remedy for the OU was protective of human health and the environment. The Health and Safety Plan and the Contingency Plan are in place, sufficient to control risks, and properly implemented. Ground water extraction and treatment are effectively controlling the migration of contaminants, and reducing contaminant concentrations in the subsurface as needed to meet cleanup standards in the timeframe anticipated at the time of the ROD. Institutional controls are in place to prevent use of contaminated ground water.

No deficiencies in the remedy were identified during the 2007 Five-Year Review.

5.2. Recommendations and Follow-up Actions from the 2007 Five-Year Review

The following recommendations were developed during the Five-Year Review process in 2007:

1. DOE/NNSA recommend implementing monitored natural attenuation as a health-protective, cost effective final remedy for nitrate in ground water.
2. A land use control will be added that prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition will be included in the Final Site-Wide ROD scheduled for 2008. The Final Site-Wide ROD will also reference the LLNL Site 300 Integrated Strategic Plan or other appropriate institutional planning document into which this prohibition will be incorporated.
3. The action-specific ARAR change identified in Section 6.2 of the 2007 Five-Year Review, and ARARs related to ground water cleanup, will be included in the Final Site-Wide ROD scheduled for 2008.

4. Once the extraction wellfields in the HEPA OU have operated long enough for capture zones to fully develop, DOE/NNSA will evaluate the extent of capture and the ability of the extraction wellfield to achieve ground water RAOs. This evaluation will be based on ground water elevation contours and concentration trends in extraction, performance monitoring, and guard wells. If data from this evaluation indicate that the existing extraction wellfield will not achieve ground water RAOs, modifications to the wellfield will be considered. Modifications may include changes to the extraction well pumping strategy and/or installing additional extraction wells.

No other follow-up actions were identified related to the 2007 Five-Year Review.

5.3. Results of Implemented Actions

The status of actions taken in response to the recommendations listed in Section 5.2 are as follows:

1. Monitored natural attenuation was selected as a final remedy for nitrate in ground water in the 2008 Final Site-Wide ROD.
2. A land use control that prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use was codified in the 2008 Final Site-Wide ROD.
3. The action-specific ARAR change identified in Section 6.2 was the California Code of Regulations, Title 22, Section 67391.1, adopted April 19, 2003. It contains requirements for imposing legal limitations on future site uses and activities through a land use covenant. A land use control that prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use was codified in the 2008 Final Site-Wide ROD.
4. During this review period, DOE/NNSA evaluated the extent of hydraulic capture and the ability of the existing extraction wellfield to achieve ground water RAOs based on ground water elevation contours and concentration trends in extraction, performance monitoring, and guard wells. Hydraulic capture zones were developed using observed ground water elevations and, where no data are available, an estimation of drawdown based on the Thiem equation for steady-state flow in a confined aquifer. Hydraulic capture in the $Tnbs_2$ HSU has also been evaluated through modeling studies that are documented in Appendix A of this report. As a result of this analysis, additional extraction well(s) to increase hydraulic capture are recommended as discussed in Sections 6.4.1 and 9.

5.4. Status of Other Prior Issues

There are no other prior issues.

6. Five-Year Review Process

6.1. Notification of Review/Community Involvement

The report will be placed in the Administrative Record file and the Information Repositories located in the LLNL Discovery Center in Livermore, California and in the Tracy Public Library in Tracy, California. Notice of its initiation and completion will be placed in two publications: *The Tracy Press* and *East County Times*. The initial notice was published in *The Tracy Press* and *East County Times* on X and X, respectively. [Note: the dates of the public notices will be filled in once the draft document is completed and the notices are sent to the newspapers.] Completed documents can also be accessed electronically at LLNL's Environmental Restoration Department electronic library web page at http://www-erd/library/ or the Environmental Community Relations web page at http://www-envirinfo.llnl.gov.

The draft, draft final, and final Five-Year Review is also submitted to the community action group, Tri-Valley Communities Against a Radioactive Environment, for review.

6.2. Identification of Five-Year Review Team Members

The Five-Year Review of the HEPA OU at LLNL Site 300 was led by Claire Holtzapple, Site 300 Remedial Project Manager for the DOE/NNSA-Livermore Site Office. The following team members assisted in the review:

- Leslie Ferry, Program Leader, LLNS.
- Valerie Dibley, Deputy Program Leader, LLNS.
- Vic Madrid, Hydrogeology Team Leader, LLNS.
- Anne Helmig, Hydrogeologist, Weiss Associates.
- John Valett, Hydrogeologist, Weiss Associates.

6.3. Document Review

This Five-Year Review consisted of examining relevant project documents and site data:

- Final Site-Wide Remedial Investigation for Lawrence Livermore National Laboratory Site 300 (Webster-Scholten et al., 1994).
- Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300 (Ferry et al., 1999).
- Interim Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300 (U.S. DOE, 2001).
- Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300 (U.S. DOE, 2008).
- Remedial Design Work Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300 (Ferry et al., 2001b).
- Interim Remedial Design for the HEPA Operable Unit at Lawrence Livermore National Laboratory Site 300 (Madrid et al., 2002).

- Five-Year Review Reports for the HEPA Operable Unit Lawrence Livermore National Laboratory Site 300 (Dibley et al., 2007b).
- Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300 (Ferry et al., 2006).
- Semi-annual Site-Wide Compliance Monitoring Reports that include evaluations of remediation progress in the HEPA OU (Dibley et al., 2007d, 2008c, 2009c, 2009d, 2010a, 2010b, 2011a, and 2011c; LLNL 2008).

This Five-Year Review evaluates subsurface contaminant concentration and remediation system performance data collected through the first semester of calendar year 2011.

6.4. Data Review and Evaluation

A review and evaluation were conducted of data collected during this review period to determine progress in: (1) remediating ground water to meet cleanup standards (Section 6.4.1), and (2) mitigating risk to onsite workers from exposure to VOCs in subsurface soil and surface water (Section 6.4.2.).

6.4.1. Ground Water Remediation Progress

This section is organized into three subsections: mass removal (Section 6.4.1.1), contaminant concentrations, distribution, and remediation (Section 6.4.1.2), and capture zone analysis (Section 6.4.1.3).

6.4.1.1. Mass Removal

Figures 9, 10, and 11 show the cumulative mass of VOCs, RDX, and perchlorate respectively, removed from ground water by treatment facilities in the HEPA OU. The contaminant mass removed by the HEPA OU ground water extraction and treatment facilities since remediation began include:

- The 815-SRC GWTS has removed over 0.12 kg of VOCs, 1.4 kg of RDX, and 250 g of perchlorate from ground water.
- The 815-PRX GWTS has removed over 0.71 kg of VOCs and 150 g of perchlorate from ground water. Total VOC mass removal is greatest at this treatment facility due to the combination of relatively high COC concentrations and extraction wells that can sustain continuous pumping. High explosives compounds such as RDX have not routinely been detected in the 815-PRX extraction wells.
- The 815-DSB GWTS has removed 0.48 kg of VOCs from ground water. Because only very low VOC concentrations are present in ground water at the leading edge of the plume, high mass removal rates are not expected.
- The 817-SRC GWTS has removed over 3.1 g of perchlorate and 0.0052 kg of RDX from ground water. Due to the very low yields in this area, cumulative mass removal rates are small at 817-SRC as compared to the other HEPA treatment facilities. No VOCs have been removed from this facility because the facility is upgradient of this plume.
- The 817-PRX GWTS has removed over 0.12 kg of VOCs, 260 g of perchlorate, and 0.078 kg of RDX from ground water. The 817-PRX treatment facility (Figure 11) has a

higher mass removal rate of perchlorate than other HEPA treatment facilities due to continuous extraction from W-817-03 and its location within the perchlorate plume.

- The overall mass removed by the 829-SRC GWTS is small (0.00031 kg VOCs, 0.16 g perchlorate and 1.3 kg nitrate) because this facility has very low extraction well flow rates

As the selected remedy for nitrate in the HEPA OU is MNA, following treatment to remove VOCs, HE compounds, and perchlorate, nitrate-bearing water is re-injected into the $Tnbs_2$ HSU where it undergoes *in situ* biotransformation to benign nitrogen gas (N_2) by anaerobic nitrifying bacteria. Therefore, no nitrate mass removal numbers are given for the treatment facilities.

6.4.1.2. Contaminant Concentrations, Distribution, and Remediation

At the HEPA OU, VOCs (mainly TCE, but also including 1,1-DCE, cis-1,2-DCE, and chloroform) are the primary COCs detected in ground water; RDX, HMX, 4-ADNT, perchlorate, and nitrate are secondary COCs. For the purposes of compliance monitoring, ground water COCs were designated as primary or secondary in the Site 300 Compliance Monitoring Plan. Primary COCs are those that generally exhibit: (1) higher migration rates than secondary COCs, (2) larger horizontal and vertical extent of contamination than secondary COCs, and (3) any other contaminant- or area-specific consideration that indicates that indicates that a more frequent sampling frequency is appropriate (e.g., a highly toxic contaminant.) Primary COCs are generally monitored more frequently (semi-annually) than secondary COCs (annually).

Most ground water contamination at the HEPA occurs primarily in the $Tnbs_2$ HSU. Some TCE, RDX, perchlorate, and nitrate have also been detected in the perched ground water of the Tpsg-Tps HSU in the vicinity of Buildings 815 and 817. Minor concentrations of VOCs, perchlorate, and nitrate are also present in perched ground water in $Tnsc_{1b}$ HSU in the 829-SRC area. No contamination has been detected in the Upper and Lower $Tnbs_1$ HSUs in the HEPA OU. VOC, HE compound, perchlorate, and nitrate concentrations, distribution, and remediation are discussed in Sections 6.4.1.2.1 through 6.4.1.2.4.

6.4.1.2.1. VOC Concentrations, Distribution, and Remediation

While the majority of the VOCs contamination in HEPA OU ground water is present in the $Tnbs_2$ HSU, some VOCs are also present in the Tpsg-Tps and $Tnsc_{1b}$ HSUs. Of the VOC COCs, only TCE is currently detected in HEPA ground water at concentrations above its 5 µg/L MCL cleanup standard, with the exception of 1,2-DCA that is detected in two wells located near the former 814 lagoon (W-814-01 and -2138) at concentrations of 0.75 and 0.8 µg/L; slightly above the 0.5 µg/L MCL.

As shown in Table 4, VOC-contaminated ground water extracted from the Tpsg-Tps HSU is treated at the 817-PRX GWTS. VOCs are extracted from the $Tnbs_2$ HSU and treated by the 815-SRC, 815-PRX, 815-DSB, and 817-PRX GWTSs. The 829-SRC GWTS treats VOCs in ground water extracted from the $Tnsc_{1b}$ HSU. No VOCs are treated by the 817-SRC GWTS, as its extraction wellfield is located upgradient of the VOC plume. The distribution and progress of VOC remediation in the Tpsg-Tps, $Tnbs_2$, and $Tnsc_{1b}$ HSUs are discussed below.

Tpsg-Tps HSU - Concentrations and the distribution of VOCs in the Tpsg-Tps HSU in the second semester of 2010 are presented in Figure 12. This HSU is only periodically saturated and monitor wells completed in this HSU are frequently dry. Limited recharge has led to insufficient

water for sampling in some wells completed in the Tps-Tpsg HSU. As shown in Figure 12, VOCs (mainly TCE) have been detected in the sands and gravels of the Tpsg-Tps HSU near the 815-SRC, 815-PRX and 817-PRX treatment facilities.

TCE concentrations in the Tpsg-Tps HSU have decreased from a historical maximum of 450 µg/L in 1992 to a maximum of 53 µg/L in the first semester of 2011. Remediation efforts in this HSU have been focused in the area with the highest concentrations located near 817-PRX extraction well W-817-2318. This extraction well removes ground water from the Tpsg-Tps HSU near Spring 5. Although remediation efforts are hampered by limited recharge, low ground water yield and dry conditions, concentrations of VOCs in the Tpsg-Tps HSU continue to decline. Total VOCs have remained below the 0.5 µg/L reporting limit in Tpsg-Tps well W-35C-05, located near the site boundary.

Because low concentrations of VOCs are detected in the Tpsg-Tps HSU ground water upgradient of the Building 815 source area, and the Tpsg-Tps HSU wells in the Building 815 area are frequently dry, DOE/NNSA recommends installing a new monitor well (W-815-2XM1) near 815-SRC to monitor COC concentrations in the deeper portions of the Tpsg-Tps HSU (Figure 12).

$Tnbs_2$ HSU - The majority of the VOCs contamination in HEPA OU ground water is present in the $Tnbs_2$ HSU. Total VOC concentrations in $Tnbs_2$ HSU ground water have decreased from a historic maximum concentration of 110 µg/L in extraction well W-818-08 (May 1992) to a first semester 2011 maximum total VOC concentration of 40 µg/L in the same well. Figure 13 shows the ground water potentiometric surface map for the $Tnbs_2$ HSU. The general ground water flow direction in this HSU is to the southeast. Concentrations and the distribution of VOCs and hydraulic capture zones for the 815-SRC, 815-PRX, 815-DSB, and 817-PRX GWTSs in the $Tnbs_2$ HSU in the second semester of 2010 are presented in Figure 14. The first semester hydraulic capture zones are shown on this figure because these capture zones are more representative of extraction wellfield operations during the past five years. VOCs in $Tnbs_2$ HSU ground water relative to the HEPA GWTSs are discussed below.

The objective of the 815-SRC GWTS is to remediate VOCs in the Building 815 source area. As shown in Figure 15(a), VOC concentrations in 815-SRC extraction wells have decreased from an historical maximum concentration of 31 µg/L to a maximum of 6.8 µg/L in the first semester of 2011, but showed a stabilized trend since extraction started in 2000. This is likely due to VOCs being drawn into the well during pumping. As shown in Figure 14, the highest VOC concentrations in $Tnbs_2$ HSU ground water in the HEPA OU are detected approximately 500 ft downgradient of Building 815, which is the primary source of VOC contamination in the HEPA OU ground water. Because there are no confirmed VOC release sites in this downgradient area and Building 815 is a known VOC source area, the VOC plume appears to be detached from its source and the VOC source at Building 815 is likely depleted. A comparison of the 2005 and 2010 total VOC concentrations in the $Tnbs_2$ HSU (Figure 16) shows a small increase in the extent of contamination north of W-815-04 due to the injection of ground water into W-815-1918. Since remediation began, the 815-SRC GWTS has removed over 0.12 kg of VOCs from ground water.

The 815-PRX GWTS was installed to offset pumping at the 815-DSB GWTS and capture total VOCs from upgradient sources. As shown on Figure 17(a), VOC concentrations in the 815-PRX extraction wells have decreased from a maximum historical concentration of 110 µg/L

(W-818-08, May 1992) to first semester 2011 concentration of 40 µg/L in the same well (April 2011). VOC concentrations in the 815-PRX extraction wells have stabilized in recent years as the wells continue to capture contaminated ground water from upgradient (Figure 14). Extraction wells W-818-08 and W-818-09 display the "NS" for No Sample on Figure 14 because the facility was undergoing major maintenance during the second semester 2010 sampling event. As shown on Figure 14, TCE is the only VOC currently present in these extraction wells. A comparison of the distribution of VOCs in the second semester 2005 versus the second semester 2010 (Figure 16) shows little difference in the extent or magnitude of contamination near the 815-PRX extraction wells due to their location downgradient of the source areas. Based on Figure 16 and declining concentration trends in nearby monitor well W-814-02, total VOC concentrations have decreased near 815-PRX injection well W-814-2134 as the total VOC plume continues to be cleaned up and to move downgradient. Since remediation began, the 815-PRX GWTS has removed over 0.71 kg of VOCs from ground water.

The primary objective of the 815-DSB GWTS is to prevent offsite VOC plume migration in the $Tnbs_2$ HSU, therefore, the most indicative measure of progress is concentration trends in downgradient guard wells. In the early years of operation, VOCs were sporadically detected at a maximum concentration of 1.5 µg/L in guard wells W-35B-02, W-35B-03, W-35B-04 and W-35B-05. As a result, the extraction well flow rate was increased and an additional extraction well was added to the wellfield to increase hydraulic capture. In addition, the facility was converted from solar power to site power to ensure continuous operation. Since these modifications, VOCs have been infrequently detected at low concentrations (<1 µg/L) in guard well W-35B-04, but only after the facility has been offline for repairs. Because the 815-DSB GWTS is located at the leading edge of the VOC plume, its extraction wells capture upgradient TCE-contaminated ground water. This phenomenon is shown by time-series plots of VOC concentrations in the 815-DSB extraction wells, which show increasing TCE concentrations over time (Figure 18). Pumping at 815-DSB has been successful in minimizing offsite migration of TCE and in reducing contamination near offsite water-supply well GALLO1. However some of the increase in TCE exhibited near the 815-DSB treatment facility is probably due to TCE migrating from sources located in Building 832 Canyon. As of the first semester 2011, the 815-DSB GWTS has removed 0.48 kg of VOCs from ground water (Figure 9). Because only very low VOC concentrations are present in ground water at the leading edge of the plume, high mass removal rates are not expected. $Tnbs_2$ guard wells W-815-2110 and W-815-2111 were installed in 2005 to monitor pumping at offsite water-supply well GALLO1. Because offsite pumping tends to pull VOCs towards GALLO1, VOCs are commonly detected in guard wells W-815-2110 and W-815-2111 at concentrations of less than 3 µg/L. Historically, low concentrations of TCE (< 1 µg/L) have sporadically been detected in GALLO1; however, since pumping at 815-DSB has increased, these detections are less common and usually only occur after the 815-DSB treatment facility has been offline. During the first semester 2011, VOC concentrations were below the 0.5 µg/L reporting limit in fourteen routine and duplicate monthly samples collected from offsite water-supply well GALLO1.

No VOCs are treated by the 817-SRC GWTS, as its extraction wellfield is located upgradient of the VOC plume.

The 817-PRX GWTS was installed to offset pumping at the 815-DSB GWTS and capture total VOCs from upgradient sources. As shown on Figure 19(a), VOC concentrations in the 817-PRX extraction wells have decreased from a maximum historical concentration of 36 µg/L

(W-817-03, April 1989) to first semester 2011 concentration of 11 µg/L (W-817-04, March 2011). Concentrations in all extraction wells display an initial decline followed by a period of relatively stable values as contaminants continue to be captured by the extraction wells. $Tnbs_2$ HSU ground water was initially extracted from wells W-817-03 and W-817-04; however, W-817-04 was converted to a monitor well in late 2007 due to low yields. In 2010, a new well, W-817-2609, was installed south of W-817-03. The well was initially considered to be an extraction well candidate. However, preliminary hydraulic tests showed that this monitor well has low yields, and as a result, W-817-2609 will remain a monitor well. To increase hydraulic capture near the 817-PRX treatment facility, flow rates were recently increased at extraction well W-817-03 for a total combined flow of 2.5 gpm. This flow rate is currently constrained by the maximum injection capacity of the two 817-PRX injection wells. Mass removal performance will be monitored at 817-PRX to determine whether additional facility upgrades (e.g., increased injection well capacity) are warranted to enable increased pumping from well W-817-03. As shown on Figure 16, the 817-PRX treatment facility has not yet had a significant impact on the lateral extent of total VOCs plume in the $Tnbs_2$ HSU. Since remediation began, the 817-PRX GWTS has removed over 0.12 kg of VOCs from ground water (Figure 9).

Figure 16 compares the existing extraction wells and the distribution of total VOCs in ground water in the $Tnbs_2$ HSU in the second semester 2005 versus second semester 2010. Overall, the extent of VOC contamination in $Tnbs_2$ ground water has not changed significantly except near the southern end of 832 Canyon where the spatial distribution of total VOCs appears to have increased due to the presence of an additional contouring location, extraction well W-830-2216. Although the extent of the VOC plumes in the HEPA did not change significantly, the total VOC and RDX concentrations within the plumes continue to decline.

$Tnsc_{1b}$ HSU - The objective of the 829-SRC extraction and treatment system is to reduce VOC concentrations in $Tnsc_{1b}$ HSU ground water (Figure 20). As shown on Figure 21(a), VOC concentrations in ground water collected from 829-SRC extraction well W-829-06 ($Tnsc_{1b}$ HSU) have decreased from a historic maximum of 1,013 µg/L (August 1993) to a first semester 2011 maximum total VOC concentration of 8.1 µg/L (March). To help flush contaminants from this shallow perched water zone, ground water is extracted from well W-829-06, treated, and injected into well W-829-08. Because this facility has very low extraction well flow rates, the overall mass removal is small (0.00031 kg VOCs). The facility was offline during 2009 for an engineering evaluation and upgrade that resulted in a change in the treatment train for nitrate removal (Ferry et al., 2010).

6.4.1.2.2. HE Compound Concentrations, Distribution, and Remediation

HE compounds are detected primarily in the $Tnbs_2$ HSU in the HEPA (Figure 22). While RDX has historically been detected in Tpsg-Tps HSU ground water, it is not currently detected in this HSU. No HE compounds have been detected in $Tnsc_{1b}$ HSU ground water.

As shown in Table 4, HE-contaminated ground water extracted from the $Tnbs_2$ HSU is treated at the 815-SRC, 817-SRC, and 817-PRX GWTS. No HE compounds are treated by the 815-PRX, 815-DSB, or 829-SRC facilities as their extraction wellfields are outside the extent of the RDX plume. The distribution and progress of HE compound remediation in the Tpsg-Tps and $Tnbs_2$, HSUs are discussed below.

Tpsg-Tps HSU – During the first semester 2011, RDX was not detected at concentrations above the 1 µg/L reporting limit in any ground water samples collected from the Tpsg-Tps HSU.

However, this HSU is only periodically saturated and monitor wells completed in this HSU are frequently dry. The historic maximum RDX concentration detected in ground water collected from the Tpsg-Tps HSU was 350 µg/L (March 1988) from well W-815-01; this well has been dry since 1999. More recently, RDX was detected in ground water collected from monitor well W-815-03 at a concentration of 100 µg/L (April 2003).

$Tnbs_2$ HSU - The 815-SRC GWTS treats RDX in ground water that has migrated to this area from the rinsewater lagoon sources at Buildings 806 and 807. As shown on Figure 15(b), RDX concentrations in groundwater in the 815-SRC extraction wells have decreased from a historical maximum concentration of 170 µg/L in extraction well W-815-04 to a February 2011 concentration of 9.2 µg/L. RDX concentrations in ground water collected from extraction well W-815-02 remain above 50 µg/L due in part to the tendency for RDX to sorb to the media rather than be transported in a dissolved phase. Both extraction wells showed a significant decrease in RDX concentrations following the start of ground water extraction and treatment in 2000. Figure 23 compares the distribution of RDX in the $Tnbs_2$ HSU in the second semester of 2005 versus the second semester of 2010. The extent and magnitude of RDX contamination in the $Tnbs_2$ HSU has not changed significantly during the past five years; however, concentrations in monitor well W-809-03 have increased due to the injection of groundwater into nearby well W-815-1918. As shown on the time series plot of cumulative mass removed (Figure 10), the 815-SRC treatment facility accounts for most of the RDX removed in the HEPA due to the high concentrations present and the tendency for RDX to sorb onto the media. Since remediation began, the 815-SRC GWTS has removed over 1.4 kg of RDX from ground water. HMX was detected during the first semester 2011 in several ground water samples collected from 815-SRC wells, including extraction wells W-815-02 and W-815-04.

In March 2011, RDX was detected for the first time at a low concentration (2 µg/L) in 815-PRX extraction well W-818-09. No HE compounds were found in nearby extraction well W-818-08. In the future, monitoring for HE compounds will continue in these extraction wells and the frequency of sampling may be increased if detections in ground water continue.

The maximum historic RDX concentration detected in $Tnbs_2$ HSU groundwater was 204 µg/L measured in 1992 in 817-PRX extraction well W-817-01. As shown in Figure 24(a), RDX concentrations in extraction well W-817-01 have decreased from the 204 µg/L1992 historical maximum to a concentration of less than 50 µg/L in the first semester of 2011. In recent years, RDX concentrations have been relatively stable as the extraction well continues to pull in contaminated ground water from upgradient (Figure 24[a]). Decreasing maximum RDX concentrations have generally been observed in $Tnbs_2$ HSU near both the Building 815 and 817 source areas. HE compounds are relatively immobile and due to remediation efforts, the extent of RDX contamination at the leading edge of the $Tnbs_2$ HSU plume (east of 817-PRX) has remained relatively stable. During the first semester 2011, RDX was not detected at concentrations above the 1 µg/L reporting limit in any samples collected from $Tnbs_2$ HSU guard wells. HMX is also detected in $Tnbs_2$ HSU ground water in the 817-PRX area. HMX concentrations have decreased from a historic maximum of 57 µg/L (1995) in the 817-PRX extraction well W-817-01 to a maximum of 17 µg/L in the first semester 2011 in the same well. Since remediation began, the 817-SRC GWTS has removed 0.0052 kg of RDX from ground water. Due to the very low yields in this area, cumulative mass removal rates are small at 817-SRC as compared to the other HEPA treatment facilities.

The HE compound 4-ADNT has been detected sporadically in $Tnbs_2$ HSU ground water. The highest historic concentration of 4-ADNT detected in HEPA was 24 µg/L, measured in the 817-SRC extraction well W-817-01 in September 1997. 4-ADNT was also detected at a concentration of 7.5 µg/L in an influent sample to the 815-SRC GWTS in July 2008. During the first semester 2011, 4-ADNT was detected above the 2 µg/L reporting limit in two $Tnbs_2$ wells at concentrations of 9.3 µg/L in W-809-03 and 2.4 µg/L in W-818-11. During the first semester 2011, 4-ADNT has never been detected above the 2 µg/L reporting limit any Tpsg-Tps or $Tnsc_{1b}$ HSU wells.

In April 2008, nitrobenzene was detected for the first time in the HEPA $Tnbs_2$ ground water in a sample from the 817-SRC extraction well W-817-01 at a concentration of 6.2 µg/L, and in a sample collected from the influent to the 815-SRC GWTS at a concentration of 4.1 µg/L. Nitrobenzene was not detected above its reporting limit in subsequent samples collected from W-817-01 and the influent to 815-SRC GWTS. During the first semester 2011, nitrobenzene was not detected above the 2 µg/L reporting limit in any HEPA ground water samples.

6.4.1.2.3. Perchlorate Concentrations, Distribution, and Remediation

Perchlorate is detected in the Tpsg-Tps, $Tnbs_2$, and $Tnsc_{1b}$ HSU in the HEPA (Figure 25 and 27). Most perchlorate contamination at the HEPA occurs primarily in the $Tnbs_2$ HSU. Perchlorate has also been detected in the perched ground water of the Tpsg-Tps HSU in the vicinity of Buildings 815 and 817. Minor concentrations of perchlorate are also present in $Tnsc_{1b}$ HSU ground water in the 829-SRC area.

Tpsg-Tps HSU - As shown in Figure 25, perchlorate is detected in the Tpsg-Tps HSU ground water at a concentration exceeding the 6 µg/L MCL cleanup standard in only one well in the HEPA. During the first semester 2011, the maximum perchlorate concentration detected in Tpsg-Tps HSU ground water was 14 µg/L in 817-PRX extraction well W-817-2318. The historic maximum perchlorate concentration detected was 17 µg/L (2008) in the same well. Ground water from this well is extracted and treated at the 817-PRX GWTS to remove perchlorate.

$Tnbs_2$ HSU - As shown on Figure 26 significant progress has been made in cleaning up perchlorate in the $Tnbs_2$ HSU during the past five years. This figure compares the existing extraction wells and the distribution of perchlorate in ground water in the $Tnbs_2$ HSU in the second semester 2004 and the second semester 2010. Perchlorate data from the second semester of 2004 was used rather than 2005 as the 2004 data is more representative of the historical perchlorate distribution. Perchlorate concentrations have decreased in $Tnbs_2$ ground water from a historic maximum of 50 µg/L (W-817-01, February 1998) to a first semester 2011 maximum concentration of 29 µg/L in the same well.

As shown on Figure 15(c), perchlorate concentrations have decreased in both 815-SRC extraction wells, and perchlorate concentrations in W-815-04 are now below the 4 µg/L detection limit. Perchlorate concentrations near 815-SRC began to decline after the installation of an upgradient injection well W-815-1918. Overall, perchlorate concentrations in the 815-SRC extraction wells decreased from a historical maximum concentration in ground water of 24 µg/L in extraction well W-815-02 to a first semester 2011 maximum concentration of 8.1 µg/L in the same well. Since remediation began, the 815-SRC GWTS has removed over 250 g of perchlorate from ground water.

While perchlorate concentrations in 815-PRX extraction wells (Figure 24[b]) have been stable with concentrations remaining in the range of 6 to 10 µg/L, the area with the highest perchlorate concentrations has decreased significantly in the $Tnbs_2$ HSU (Figure 27). Perchlorate has not been detected in downgradient monitor wells, indicating that the 815-PRX extraction wells are adequately capturing the perchlorate plume in this area and preventing migration toward the site boundary. Since remediation began, the 815-PRX GWTS has removed over 150 g of perchlorate from ground water.

No perchlorate is treated by the 815-DSB GWTS, as its extraction wellfield is located downgradient of the perchlorate plume.

As shown in Figure 24(b), perchlorate concentrations in 817-SRC extraction well W-817-01 have decreased from a historical maximum of 50 µg/L in 1998 to a concentration of less than 29 µg/L in the first semester of 2011. More recently, perchlorate concentrations have been relatively stable as the extraction well continues to pull in contaminated ground water from upgradient (Figure 27). As shown on Figure 27, extraction well W-817-01 has helped reduce the overall extent of the perchlorate plume in this area. Since remediation began, the 817-SRC GWTS has removed 3.1 g of perchlorate from ground water. DOE/NNSA recommend installing a new monitor well W-817-2XM1 (Figure 24) in the $Tnbs_2$ HSU between the 817-SRC injection and extraction wells to assess the effectiveness of the 817-SRC recirculation cell between extraction well W-817-01 and effluent injection well W-817-06A.

As shown in Figure 19(c), the concentrations of perchlorate in the 817-PRX extraction wells display an initial decline followed by a period of relatively stable values as contaminants continue to be pulled in by the extraction wells. As discussed in Section 6.4.1.2.1, flow rates were recently increased at 817-PRX extraction well W-817-03. Mass removal performance will be monitored at 817-PRX to determine whether additional facility upgrades (e.g., injection well capacity) are warranted to enable increased pumping from well W-817-03. Since remediation began, the 817-PRX GWTS has removed 260 g of perchlorate from ground water. The 817-PRX treatment facility has a higher mass removal rate of perchlorate than other HEPA treatment facilities due to continuous extraction from W-817-03 and its location within the perchlorate plume. As shown on Figure 27, the 817-PRX treatment facility has helped to decrease the extent of the perchlorate plume in the $Tnbs_2$ HSU.

Overall, perchlorate concentrations continue to decline and the southwestern plume front has been receding due to continued 817-PRX and 817-SRC operations. To the north, the $Tnbs_2$ HSU perchlorate plume has been declining based on concentration trends observed in monitor well W-809-03 and in 815-SRC extraction wells W-815-02 and W-815-04. Previously, an increasing trend was observed in this area as a result of the mobilization of perchlorate by injection of treated ground water into nearby 815-SRC injection well W-815-1918. Perchlorate was not detected in any of the $Tnbs_2$ HSU guard wells during the first semester 2011.

$Tnsc_{1b}$ HSU - Perchlorate concentrations in 829-SRC $Tnsc_{1b}$ HSU extraction well W-829-06 have decreased from a historic maximum of 29 µg/L (December 2000) to a concentration of 7.2 µg/L in the first semester 2011; slightly above the 6 µg/L cleanup standard. Perchlorate was not detected at concentrations above its 4 µg/L reporting limit in the most recent samples collected from $Tnsc_{1b}$ HSU monitor wells W-829-08 and W-829-1940.

6.4.1.2.4. Nitrate Concentrations, Distribution, and Remediation

The remedy selected for nitrate in HEPA ground water was monitored natural attenuation based on a study conducted by DOE/NNSA. The study results indicated that denitrification processes are naturally attenuating nitrate in the confined, oxygen-depleted region of the $Tnbs_2$ HSU in the HEPA OU as discussed below:

- Both nitrate and dissolved oxygen concentrations in ground water decrease significantly as ground water flows from unconfined to confined conditions in the $Tnbs_2$ HSU.
- Low dissolved oxygen concentrations in the downgradient, confined region of the $Tnbs_2$ HSU are conducive for anaerobic bacteria to metabolize nitrate, converting it to harmless N_2 gas.
- Stable isotope signatures (i.e., $\delta^{15}N$ and $\delta^{18}O$) of nitrate in ground water indicate a trend of isotopic enrichment that is characteristic of denitrification.
- Dissolved nitrogen gas concentrations, the product of denitrification, are highly elevated in nitrate-depleted ground water in the confined region of the $Tnbs_2$ HSU (Beller et al., 2004).

Figures 28 and 29 show the distribution of nitrate in ground water collected in the Tpsg-Tps HSU and the $Tnbs_2$ HSU, respectively, during the first semester 2010.

As shown in Figure 28, the maximum nitrate concentration detected in ground water in the Tpsg-Tps HSU during the first semester 2011 was 550 mg/L (W-6CS, February). Because there are no known septic systems or other Site 300 operations representing potential nitrate sources near this well, these elevated nitrate levels are probably related to a pre-Site 300 sheep ranch that was discovered in a historic photo of the area. Ground water sampled from all other wells completed in the Tpsg-Tps HSU had significantly lower nitrate concentrations. The highest nitrate concentration found in other wells completed in this HSU was 160 mg/L (817-PRX extraction well W-817-2318, April 2011). Nitrate-bearing ground water extracted from 817-PRX extraction well W-817-2318 is re-injected, following treatment to remove VOCs and perchlorate, into the $Tnbs_2$ HSU where the nitrate will naturally attenuate. The Tpsg-Tps HSU is variably saturated with primarily seasonal, discontinuous lenses of perched ground water of limited extent. As a result, when ground water is present in this HSU, nitrate will be limited to the extent of saturation in this HSU. Nitrate concentrations in Tpsg-Tps HSU wells located near the site boundary (W-35C-01, W-35C-05, and W-4AS) have been low (<0.5 to 1.8 mg/L) throughout their sampling history.

In the $Tnbs_2$ HSU, nitrate concentrations typically ranging from 70 to 100 mg/L have been reported in upgradient wells completed in the unconfined portions of the HSU and lower and constant nitrate concentrations typically ranging from less than 0.1 to 3 mg/L have been observed in the downgradient, confined portions of the HSU. This pattern suggests that a balance exists between the rates of nitrate loading in the upgradient, unconfined region of the $Tnbs_2$ HSU and the rates of nitrate removal by denitrification in the downgradient, confined region of the HSU. Anaerobic bacteria present in the oxygen-depleted, confined region of the $Tnbs_2$ HSU provides the main mechanism for denitrification. Due to microbial denitrification, nitrate concentrations remain below the 45 mg/L cleanup standard in all wells near the southern site boundary where the ground water exists under confined conditions.

Nitrate concentrations in HEPA ground water continue to support the interpretation that nitrate is being degraded *in situ* by natural processes. Natural attenuation is demonstrated through multiple independent data sets: (1) oxygen-depleted, nitrate-reducing geochemical conditions, (2) isotopic enrichment in nitrogen-15, (3) excess dissolved nitrogen gas in ground water with low to non-detectable nitrate concentrations, and (4) reduced nitrate concentrations in the oxygen-depleted, confined region of the $Tnbs_2$ HSU.

The distributions of nitrate in ground water in the HEPA support the presence of the elements important for an MNA remedy: (1) the contamination does not pose an unacceptable risk, (2) nitrate concentrations remain below the 45 mg/L cleanup standard in all wells near the southern site boundary where onsite and offsite water-supply wells are located, and (3) nitrate concentration contours are stable.

6.4.1.3. Capture Zone Analysis

Hydraulic capture of HEPA ground water COCs by the 815-SRC, 815-PRX, 815-DSB, 817-SRC, and 817-PRX extraction wellfields was evaluated to determine the effectiveness of the extraction wells, and if adjustments to well operations (i.e., pumping rates) and/or wellfield expansions could improve remediation effectiveness. Capture zone analysis results are discussed by GWTS areas in Sections 6.4.1.3.1 through 6.4.1.3.5. DOE/NNSA recommendations for wellfield optimization are presented in Section 6.4.1.3.6.

6.4.1.3.1. Capture Zone Analysis at 815-SRC

Contaminant mass removal in 815-SRC area is limited due to low extraction well yields. As a result, DOE/NNSA began reinjecting treated effluent upgradient to increase the hydraulic gradient and flush contaminants toward the extraction wells.

Figure 30 displays the zones of hydraulic capture and injection influence as estimated using the Thiem equation for steady-state radial flow to a well and pumping rates during the first semester 2010. The capture zones are a conservative estimate of hydraulic capture and are representative of operations during the past five years.

To increase hydraulic capture in areas with high RDX and perchlorate concentrations between the 815-SRC and 817-SRC treatment facilities, DOE/NNSA recommends installing a new extraction well west of W-815-02. The new extraction well would be connected to the 815-SRC GWTS for VOC, RDX, and perchlorate removal. The location of this proposed well (W-815-2803) is shown on Figure 30.

Future estimates of ground water capture by the 815-SRC extraction wellfield, including proposed new extraction well W-815-2803, are presented in Figure 14. The Figure 30 capture zones show the extent of hydraulic capture after 5 years of pumping the "As Designed" extraction wellfield as predicted using a FEFLOW model (Appendix A). The "As Designed" extraction wellfield includes pumping from all twelve HEPA extraction wells including the existing 815-SRC extraction wells W-815-02 and W-815-04 and proposed new extraction well W-815-2803. As presented on Figure 30, the addition of proposed extraction well W-815-2803 increases hydraulic capture of VOCs, RDX and perchlorate near 815-SRC. After the new 815-SRC extraction well is installed and connected, hydraulic capture in the $Tnbs_2$ HSU will be re-evaluated.

6.4.1.3.2. Capture Zone Analysis at 815-PRX

Contaminant mass removal in the 815-PRX area has generally been effective in removing VOCs and perchlorate. Figure 30 displays the zones of hydraulic capture for the 815-PRX extraction wells W-818-08 and W-818-09 and influence of the injection well W-814-2134 as estimated using the Thiem equation for steady-state radial flow to a well and average pumping rates during the first semester 2010. The capture zones presented in Figure 10 are a conservative estimate of hydraulic capture. They are smaller than is typical for the 815-PRX extraction wellfield because these wells were offline during part of the 2nd semester 2010 (on which the data presented in Figure 30 is based) resulting in a lower average yield. In 2010, pumping rates from extraction wells W-818-08 and W-818-09 were increased to expand the hydraulic capture of VOCs and perchlorate in this area.

Future estimates of ground water capture by the 815-PRX extraction wellfield are presented in Figure 30. The Figure 30 capture zones show the extent of hydraulic capture after 5 years of pumping the "As Designed" extraction wellfield as predicted using a FEFLOW model (Appendix A). The "As Designed" extraction wellfield includes pumping from all twelve HEPA extraction wells including increased flow rates at the 815-PRX extraction wells W-818-08 and W-818-09.

6.4.1.3.3. Capture-Zone Analysis at 815-DSB

Figure 30 displays the zones of hydraulic capture and injection influence in the $Tnbs_2$ HSU as estimated using the Thiem equation for steady-state radial flow to a well and pumping rates during the first semester 2010. The capture zones are a conservative estimate of hydraulic capture and are representative of operations during the past five years.

To increase hydraulic capture of VOCs at the site boundary and further prevent offsite plume migration, flow rates have been increased recently in extraction wells W-35C-04 and W-6ER. In addition, DOE/NNSA recommends converting monitor well W-815-2608 to an extraction well and connecting it to the 815-DSB facility. Monitor W-815-2608, is a low flow well, which is expected to be pumped at a rate of 0.5 gpm. DOE/NNSA also recommends evaluating monitor well W-815-2621 to determine the feasibility of converting this well to an extraction well. Monitor well W-815-2621 is expected to a high flow well, which would be pumped at an extraction rate of 5 gpm, if connected. The location of wells W-815-2608 and W-815-2621 are shown on Figure 30.The 815-DSB extraction wellfield expansion is currently scheduled to be completed in 2013.

The addition of new extraction well W-815-2608 and possibly W-815-2621, together with the increased flow rates at existing extraction wells W-35C-04 and W-6ER are expected to increase hydraulic capture near the site boundary, while avoiding pulling contaminants downgradient. Increased pumping from the 815-DSB extraction wellfield will also help to offset the impact of intermittent pumping at offsite water-supply well Gallo 1.

Future estimates of ground water capture by the 815-DSB extraction wellfield are presented in Figure 30. The Figure 30 capture plots show the extent of hydraulic capture after 5 years of pumping the "As Designed" extraction wellfield as predicted using a FEFLOW model. The "As Designed" extraction wellfield includes pumping from all twelve HEPA extraction wells including the existing 815-DSB extraction wells W-35C-04 and W-6ER, and the recommended new extraction well W-815-2608 (and potential new extraction well W-815-2621). A detailed

description of the "As Designed" wellfield and associated pumping rates are described in Appendix A: Groundwater Flow and Contaminant Transport Modeling in the $Tnbs_2$ HSU.

The extent of capture by the 815-DSB extraction wellfield is expected to change significantly after the extraction wellfield is expanded and new extraction well W-815-2608 (and possibly W-815-2621) is operating. Hydraulic capture in the $Tnbs_2$ HSU will continue to be evaluated over the next five years and documented in the Annual Compliance Monitoring Reports. Based on this data, DOE/NNSA will pursue opportunities to optimize 815-DSB extraction wellfield operations to maximize contaminant removal as they are identified. However, the pumping strategy for the ground water extraction wells at the site boundary must continue to balance pumping at 815-DSB with pumping at other upgradient areas. Over-pumping of ground water from wells at the site boundary could result in more rapid migration of upgradient contamination towards the site boundary and could lengthen cleanup times for this area.

6.4.1.3.4. Capture Zone Analysis at 817-SRC

Contaminant mass removal in the 817-SRC area has generally been effective in removing RDX and perchlorate. But hydraulic capture has been limited in this area due to low extraction well yields. Figure 30 displays the zones of hydraulic capture and injection influence as estimated using the Thiem equation for steady-state radial flow to a well and average pumping rates during the first semester 2010. The capture zones presented in Figure 30 are a conservative estimate of hydraulic capture and are typical of 817-SRC operations during the past five years.

Future estimates of ground water capture by the 817-SRC extraction wellfield are presented in Figure 30. The Figure 30 capture zones show the extent of hydraulic capture after 5 years of pumping the "As Designed" extraction wellfield as predicted using a FEFLOW model (Appendix A). The "As Designed" extraction wellfield includes pumping from all twelve HEPA extraction wells including pumping from the 817-SRC extraction well W-817-01 and the recommended new 815-SRC extraction well W-815-2803 (discussed in Section 6.4.1.2). This extraction well will increase hydraulic capture between the 815-SRC and 817-SRC treatment facilities.

6.4.1.3.5. Capture Zone Analysis at 817-PRX

Contaminant mass removal in the 817-PRX area has generally been effective in removing VOCs, RDX and perchlorate. An additional well, W-817-2609, was installed in 2010 to increase hydraulic capture; however, the well will remain a monitor well due to low yields. Figure 30 displays the zones of hydraulic capture and injection influence as estimated using the Thiem equation for steady-state radial flow to a well and average pumping rates during the first semester 2010. The capture zones presented in Figure 30 are a conservative estimate of hydraulic capture and are typical of 817-PRX operations during the past five years.

Future estimates of ground water capture by the 817-SRC extraction wellfield are presented in Figure 30. The Figure 30 capture zones show the extent of hydraulic capture after 5 years of pumping the "As Designed" extraction wellfield as predicted using a FEFLOW model (Appendix A). The "As Designed" extraction wellfield includes pumping from all twelve HEPA extraction wells including increased pumping from 817-PRX extraction well W-817-03. This extraction well has additional flow rate capacity; however, higher flow rates are limited by the discharge capacity of the two 817-PRX injection wells.

6.4.1.3.6. Wellfield Optimization Recommendations

Based on the capture zone analysis for the HEPA facilities, DOE/NNSA recommends:

1. Installing a new extraction well (W-815-2803) and connecting it to the 815-SRC ground water treatment system to increase hydraulic capture and contaminant mass removal in the Building 815 source area and to prevent migration of VOCs, HE compounds, and perchlorate in the $Tnbs_2$ HSU.
2. Converting $Tnbs_2$ HSU monitor well W-815-2608 to an extraction well to increase hydraulic capture and prevent offsite migration of VOCs, and connect it to the 815- DSB ground water treatment system (Figure 10). The well is scheduled to be connected to the 815-DSB facility in 2012.
3. Evaluating $Tnbs_2$ HSU monitor well W-815-2621 to determine its suitability as an extraction well to increase hydraulic capture of VOCs near the site boundary.

These wells are shown on Figures 3 and 14.

Hydraulic capture for the twelve existing HEPA facility extraction wells and the recommended new extraction wells for the 815-SRC and 815-DSB facilities will be evaluated over the next five years and documented in the Annual Compliance Monitoring Reports. Based on this data, DOE/ NNSA will pursue opportunities to optimize the HEPA OU treatment area extraction wellfield operations to maximize contaminant removal as they are identified.

6.4.2. Risk Mitigation Remediation Progress

This section summarizes the results of the annual risk re-evaluation conducted for the HEPA OU to assess the progress of the remediation effort in mitigating risk to onsite workers.

The baseline human health risk assessment estimated an excess cancer risk of 5×10^{-6} to onsite workers inhaling VOCs evaporating from subsurface soil into outdoor ambient air in the vicinity of Building 815. An excess cancer risk of 1×10^{-5} was also estimated for onsite workers inhaling TCE and 1,1-dichloroethylene (DCE) volatilizing from surface water at Spring 5.

The Compliance Monitoring Plan requires that the risk associated with volatile contaminants in the subsurface migrating upward into indoor and outdoor ambient air and being inhaled by workers be re-evaluated annually using current data. DOE/NNSA, EPA, and the State regulatory agencies agreed that the risk would be considered successfully mitigated and risk management would be complete when the estimated risk is below 10^{-6} for two consecutive years. Risk re-evaluation for VOC inhalation in outdoor air near Building 815 was initiated in 2003. As reported in the 2003 and 2004 CMRs and 2007 Five-Year Review, VOC inhalation risk was below 10^{-6} in 2003 and 2004 (Dibley et al., 2004a, 2005a, and 2007b). Therefore, the risk associated with VOCs in subsurface soil has been successfully mitigated, and risk and hazard management is complete at Building 815.

DOE/NNSA were unable to re-evaluate VOC inhalation risk to onsite workers at Spring 5 from 2003 through 2011 due to lack of water in this spring. However, the baseline risk was calculated from VOC concentrations in well W-817-03A located adjacent to Spring 5 since the actual flow in the spring is generally too low to measure and the spring consists primarily of moist soil with wetland vegetation. No one regularly works in the vicinity of Spring 5 and VOC concentrations in ground water that feeds the spring have decreased from 150 μg/L in 1987 to 40 μg/L in March 2011. Therefore the cancer risk estimated in the baseline risk assessment has

decreased correspondingly over time. In addition, more than half of the estimated risk resulted from the presence of 1,1-DCE, which has not been detected in ground water in the area since 1987.

On September 28, 2011, EPA released updated toxicity values and contaminant characteristics for TCE in the Integrated Risk Information System (IRIS) (EPA, 2011). Currently, the only significant impact of this change is presumed to be on the assessment of risk for the vapor inhalation pathway. As agreed to with EPA and DTSC, DOE/NNSA have been using the DTSC Health and Environmental Risk Department (HERD) cancer Inhalation Unit Risk (IUR) for TCE of 2.0×10^{-6} in the calculation of cancer risk for TCE volatilizing from the subsurface into indoor air since 2005. The DTSC HERD cancer IUR for TCE is lower than the new (2011) EPA cancer IUR for TCE of 4.1×10^{-6}. Therefore, there are no implications for LLNL Site 300 as a result of the new EPA IUR for TCE. The new non-cancer Reference Concentration (RfC) is 2.0×10^{-6}. The risk assessment for the inhalation pathway to indoor air (Building 815) was re-evaluated using the new IUR of 4.0×10^{-6} per $\mu g/m^3$ and RfC of 2.0×10^{-3} $\mu g/m^3$. This evaluation was performed using the U.S EPA Johnson-Ettinger Model (version 3.1; 02/04 GW-ADV) updated with the new toxicity values for TCE. The resulting indoor air exposure concentration is 0.027 $\mu g/m^3$. This concentration is significantly below the air concentration of 0.5 $\mu g/m^3$ being protective at 10^{-6} cancer risk level and 2 $\mu g/m^3$ being protective of non-cancer effects for residential exposure. The industrial exposure levels are 3 $\mu g/m^3$ and 8.8 $\mu g/m^3$ for a 10^{-6} cancer risk level and non-cancer effects, respectively. An inverse calculation to determine the maximum allowable TCE concentration in ground water beneath Building 815 results in 200 µg/L for a 10^{-6} cancer risk level and 700 µg/L for non-cancer effects for an industrial exposure scenario. The outdoor air inhalation pathway would also not result in any unacceptable risk since the exposure concentration at the site is calculated to be 5.5×10^{-14} $\mu g/m^3$.

The baseline ecological assessment determined a risk from copper and cadmium existed for aquatic organisms, ground squirrels, and deer. Aquatic organisms are at risk from copper in shallow ground water at a location designated as Spring 5. The Toxicity Quotient using California Applied Action Levels exceeded 1 for copper in ground water samples from this location. Individual adult ground squirrels and individual adult and juvenile deer are at risk from ingestion of cadmium. The combined oral and inhalation pathway Hazard Quotient exceed 1 for these species, which was driven by the oral pathway.

As part of the Baseline Ecological Risk Assessment, surveys for the presence of surface water at Spring 5, and algae and macro-invertebrate bioassays were conducted to identify the true risk to aquatic organisms. No adverse impacts were found. Similarly, site-wide population surveys to identify the risk to deer and ground squirrels found no adverse impacts.

As required by the CMP/CP, available biological survey data were reviewed to identify changes in the abundance of deer or ground squirrel over time that could indicate impacts to the populations in the HEPA OU. Available survey data were also reviewed to identify the presence of special status species. The results of the most recent review are reported in the 2010 Annual CMR (Dibley et al., 2011a). Biological survey data will again be reviewed and reported on in the 2011 Annual CMR.

In addition to evaluating the available biological survey data from the HEPA OU, the CMP/CP also requires a re-evaluation of the ecological hazard associated with cadmium in

surface soil in these areas to determine if continuation of risk and hazard management measures are necessary. Part of this re-evaluation includes collecting additional surface soil samples from these areas for cadmium analysis and re-evaluating the associated ecological hazard. Soil sampling is scheduled for fall 2011 and will be reported in the Annual CMR.

A Site-Wide Five-Year Ecological Review was performed in 2008 (Dibley et al., 2009c). No new ecological hazards were identified in the HEPA OU, although chloride in Spring 14 was identified as requiring future review. No information was identified during this review to question the ecological protectiveness of the remedy.

6.5. Interviews and Site Inspection

DOE/NNSA meets monthly with the EPA, RWQCB, and DTSC Remedial Project Managers (RPMs) and quarterly with a community action group at Technical Assistance Grant Meetings to discuss remediation activities, issues, and cleanup status and progress.

There is a continuous presence of Site 300 Environmental Restoration Program staff at Site 300 that routinely inspect the: (1) extraction wellfield and treatment facilities weekly, and (2) monitoring wellfield during sampling activities. The Site 300 Environmental Restoration Program conducts self-assessment inspections of facilities and DOE/NNSA conducts quarterly inspections of remediation activities at Site 300. The RWQCB RPM performs site inspections twice a year, and EPA and DTSC RPMs perform site inspections as requested. The EPA performed the construction completion inspection on February 5, 2008. The Five-Year Review Inspection was performed by DOE/NNSA on March 31, 2011. The Five-Year Review Inspection Checklist is included as Attachment A.

Operational issues and resulting corrective actions identified during routine inspections associated with the treatment systems and extraction wellfields are: (1) described in detail in the Site 300 Compliance Monitoring Reports that are issued semi-annually, and (2) discussed and presented in the RPM Project Updates that are issued prior to and discussed with the regulators at the monthly RPM meetings. The contents of the Project Updates are incorporated into the RPM meeting minutes that are distributed following the meetings.

7. Technical Assessment

The protectiveness of the interim remedy was assessed by determining if:

1. The interim remedy is functioning as intended at the time of the decision documents.
2. The assumptions used in the decision-making process are still valid.
3. Any additional information has been identified that would call the protectiveness of the interim remedy into question.

7.1. Remedy Function

The remedy was determined to be functioning as intended at the time of the decision documents because:

- Ground water extraction and treatment is reducing contaminant concentrations in the subsurface as discussed in Section 6.4.

- System operation procedures are consistent with requirements.
- Costs have generally been within budget, except when extra costs were incurred to address unanticipated problems or regulatory requests.
- Ground water extraction and treatment systems are performing as designed and will continue to be operated and optimized. Examples of types of optimization that may be considered include installing new extraction wells, adding higher capacity pumps to maximize yield and to increase hydraulic capture, and upgrading the treatment facilities to accommodate increased flow, where appropriate.
- No early indicators of potential interim remedy failure were identified.
- Institutional controls are in place. No current or planned changes in land use at the site suggest that they are not or would not be effective.

7.2. Changes to Exposure Assumptions, Toxicity Data, Cleanup Levels, and Remedial Action Objectives

The assumptions used in the decision-making process was determined to still be valid because:

- There have been no changes in risk assessment methodologies or calculations that could call the protectiveness of the remedy into question.
  - There have been no changes in exposure pathways that could call the protectiveness of the remedy into question.
  - No new or previously unidentified unacceptable risk or hazard to human health or ecological receptors has been identified.
  - There have been no changes in land, building, or water use. As discussed in Section 3.2, Site 300 will be transitioning to the Hetch-Hetchy water supply in the future.
  - No new contaminant sources have been identified. In April 2008, nitrobenzene was detected for the first time in the HEPA $Tnbs_2$ ground water in a sample from the 817-SRC extraction well W-817-01 at a concentration of 6.2 µg/L, and in a sample collected from the influent to the 815-SRC GWTS at a concentration of 4.1 µg/L. Nitrobenzene was not detected above its reporting limit in additional samples collected from W-817-01 and the influent to 815-SRC GWTS. During the first semester 2011, nitrobenzene was not detected above the 2 µg/L reporting limit in any HEPA ground water samples. DOE/NNSA continue to monitor for nitrobenzene in $Tnbs_2$ ground water in the HEPA OU.
  - No remedy byproducts have been identified.
- Changes in location-, chemical-, or action-specific ARARs or to-be-considered requirements:
  - The State of California established a Maximum Contaminant Level (MCL) (6 µg/l) for perchlorate on October 18, 2007. This action-specific ARAR and ARARs related to ground water cleanup were included in the 2008 Site-Wide ROD.

  - The EPA National Pollution Discharge Elimination System (NPDES) Pesticide Rule changed in 2011, however, no Site 300 treatment systems currently discharge to the ground surface or fall under an NPDES permit.
- Changes in toxicity and other contaminant characteristics:
  - On September 28, 2011, EPA released updated toxicity values and contaminant characteristics for TCE in the IRIS. Currently, the only significant impact of this change is presumed to be on the assessment of risk for the vapor inhalation pathway. As discussed in Section 6.4.2, the Baseline Risk Assessment identified an excess cancer risk of 5×10^{-6} to onsite workers inhaling VOCs evaporating from subsurface soil into outdoor ambient air in the vicinity of Building 815 and an excess cancer risk of 1×10^{-5} for onsite workers inhaling VOCs volatilizing from surface water at Spring 5. The Building 815 risk was mitigated in 2003 and the Spring 5 risk has not been reevaluated due to lack of water since 2003. However, no one regularly works in the vicinity of Spring 5 and VOC concentrations in ground water that feeds the spring have decreased from 150 µg/L in 1987 to 40 µg/L in March 2011. The indoor and outdoor inhalation risk for Building 815 was re-evaluated using the new toxicity values. As discussed in Section 6.4.2, the new toxicity values do not result in any unacceptable cancer risk or non-cancer effects for Building 815. DOE/NNSA will review the impact of changes with the regulators and assess the need for further evaluation.
- The review found progress toward meeting the RAOs.

7.3. Other Information

No additional information was identified that would call the protectiveness of the remedy into question:

- The Health and Safety Plan and Site-Wide Contingency Plan are in place, sufficient to control risks, and properly implemented.
- No unanticipated events (i.e., natural disasters, new contaminants discovered) occurred that would call the protectiveness of the remedy into question.
- No additional information has been identified that would call the protectiveness of the interim remedy into question.
- No new technologies have been identified that are capable of accelerating or achieving cleanup in a more cost-effective manner in the HEPA OU.

8. Issues

No issues were identified during this evaluation.

9. Recommendations and Follow-Up Actions

The following recommendations were developed during the review process and will be carried out by the DOE/NNSA:

1. Install one new extraction well (W-815-2803) to increase hydraulic capture and contaminant mass removal in the Building 815 source area and to prevent migration of VOCs, HE compounds, and perchlorate in the $Tnbs_2$ HSU (Figure 10). This extraction well will be connected to the Building 815-Source (815-SRC) treatment facility. The well is scheduled to be drilled in 2012 and will be connected to 815-SRC in 2014.
2. Convert $Tnbs_2$ HSU monitor well W-815-2608 to an extraction well to increase hydraulic capture and prevent offsite migration of VOCs, and connect it to the 815-Distal Site Boundary (DSB) ground water treatment system (Figure 10). The well is scheduled to be connected to the 815-DSB facility in 2012.
3. Evaluate $Tnbs_2$ HSU monitor well W-815-2621 to determine its suitability as an extraction well for the 815-DSB wellfield.
4. Install one new well (W-817-2XM1) to monitor HE compound, perchlorate, and nitrate concentrations near the 817-SRC treatment facility in the $Tnbs_2$ HSU (Figure 10). This monitor well will assess the effectiveness of the 817-SRC recirculation cell between extraction well W-817-01 and effluent injection well W-817-06A. This well is scheduled to be drilled in 2014.
5. Install one new well (W-815-2XM1) to monitor VOCs, HE compounds, perchlorate, and nitrate concentrations near the Building 815 source area in the Tpsg-Tps HSU (Figure 20). This well is scheduled to be drilled in 2014.
6. Over the next five-years:
   - Evaluate $Tnbs_2$ HSU well W-817-2609 in the 817-Proximal area by monitoring contaminant concentrations in this well and nearby well W-817-03 to determine whether to convert well W-817-2609 to an extraction well (Figure 10).
   - Identify potential locations for two additional effluent injection wells to allow 817-PRX wellfield extraction rates to be increased in the $Tnbs_2$ HSU.

Operation of and hydraulic capture zones for existing and recommended new extraction wells in the HEPA OU will be evaluated over the next five years and documented in the Annual Compliance Monitoring Reports. Based on these data, DOE/NNSA will pursue opportunities to optimize wellfield operations to maximize contaminant removal as they are identified.

No other follow-up actions were identified related to this Five-Year Review.

10. Protectiveness Statement

The remedy at the HEPA OU is protective of human health and the environment for the site's industrial land use. The remedy protects human health because exposure pathways that could result in unacceptable risk to onsite workers are being controlled by the implementation of institutional controls, the Health and Safety Plan, and the Contingency Plan.

The cleanup standards for HEPA OU ground water are drinking water standards. Because drinking water standards do not differentiate between industrial and residential use, the ground water cleanup remedy will be protective under any land use scenario.

The cleanup standards for VOCs in subsurface soil are to reduce concentrations to mitigate risk to onsite workers and prevent further impacts to ground water to the extent technically and

economically feasible. Because some VOCs may remain in subsurface soil following the achievement of these cleanup standards, a land use control prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition is included in the Site-Wide ROD. This prohibition will remain in place until and unless a risk assessment is performed in accordance with current U.S. EPA risk assessment guidance and is agreed by the DOE/NNSA, the EPA, the DTSC, and RWQCB as adequately showing no unacceptable risk for residential or unrestricted land use.

11. Next Review

The next statutory review will be conducted within five years of the signature date of this report (2017).

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13. Acronyms and Abbreviations

1,1,1-TCA	1,1,1-Trichloroethane
ARARs	Applicable or relevant and appropriate requirements
ATA	Advanced Test Accelerator
bgs	Below ground surface
BTU	Biotreatment Unit
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	Contaminant of concern
CTR	California Toxics Rule
DCE	Dichloroethylene
DNAPL	Dense non-aqueous phase liquid
DOE	Department of Energy
DTSC	Department of Toxic Substances Control
EPA	Environmental Protection Agency
ERD	Environmental Restoration Department
ESD	Explanation of Significant Difference
ft	Feet
GAC	Granular activated carbon
Gpd	Gallons per day
gpm	Gallons per minute
GSA	General Services Area
GWTS	Ground water extraction and treatment system
HE	High explosives
HMX	High-Melting Explosive
HSU	Hydrostratigraphic unit
IRIS	Integrated Risk Information System
kg	Kilogram
LLNL	Lawrence Livermore National Laboratory
LLNS	Lawrence Livermore National Security
LNAPL	Light non-aqueous phase liquid
MCL	Maximum contaminant level
mg/kg	Milligrams per kilograms
mg/L	Milligrams per liter
MNA	Monitored natural attenuation
NNSA	National Nuclear Security Administration
O&M	Operation and maintenance
OU	Operable unit
PCBs	Polychlorinated biphenyls
PCE	Tetrachloroethylene
pCi/L	picoCuries per liter

$ppm_{v/v}$	Parts per million on a volume per volume basis
RAOs	Remedial Action Objectives
RCRA	Resource Conservation and Recovery Act
RDX	Research Department explosive
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RPMs	Remedial Project Managers
RWQCB	Regional Water Quality Control Board
SARA	Superfund Amendment Reauthorization Act
scfm	Standard cubic flow per minute
SVTS	Soil vapor extraction and treat system
TBOS/TKEBS	Tetrabutyl orthosilicate/ Tetrakis (2-ethylbutyl) silane
TCA	Trichloroethane
TCE	Trichloroethylene
TFRT	Treatment Facility Real-Time Monitoring System
THMs	Total trihalomethanes
$Tnbs_1$	Tertiary Neroly Lower Blue Sandstone
$Tnbs_2$	Tertiary Neroly Upper Blue Sandstone
$Tnsc_1$	Tertiary Neroly Lower Siltstone/Claystone
$Tnsc_2$	Tertiary Neroly Upper Siltstone/Claystone
Tps	Tertiary Pliocene nonmarine sediments
Tpsg	Tertiary Pliocene sand and gravel
U.S.	United States
VOCs	Volatile organic compounds
yd^3	Cubic yards
µg/L	Micrograms per liter

Figures

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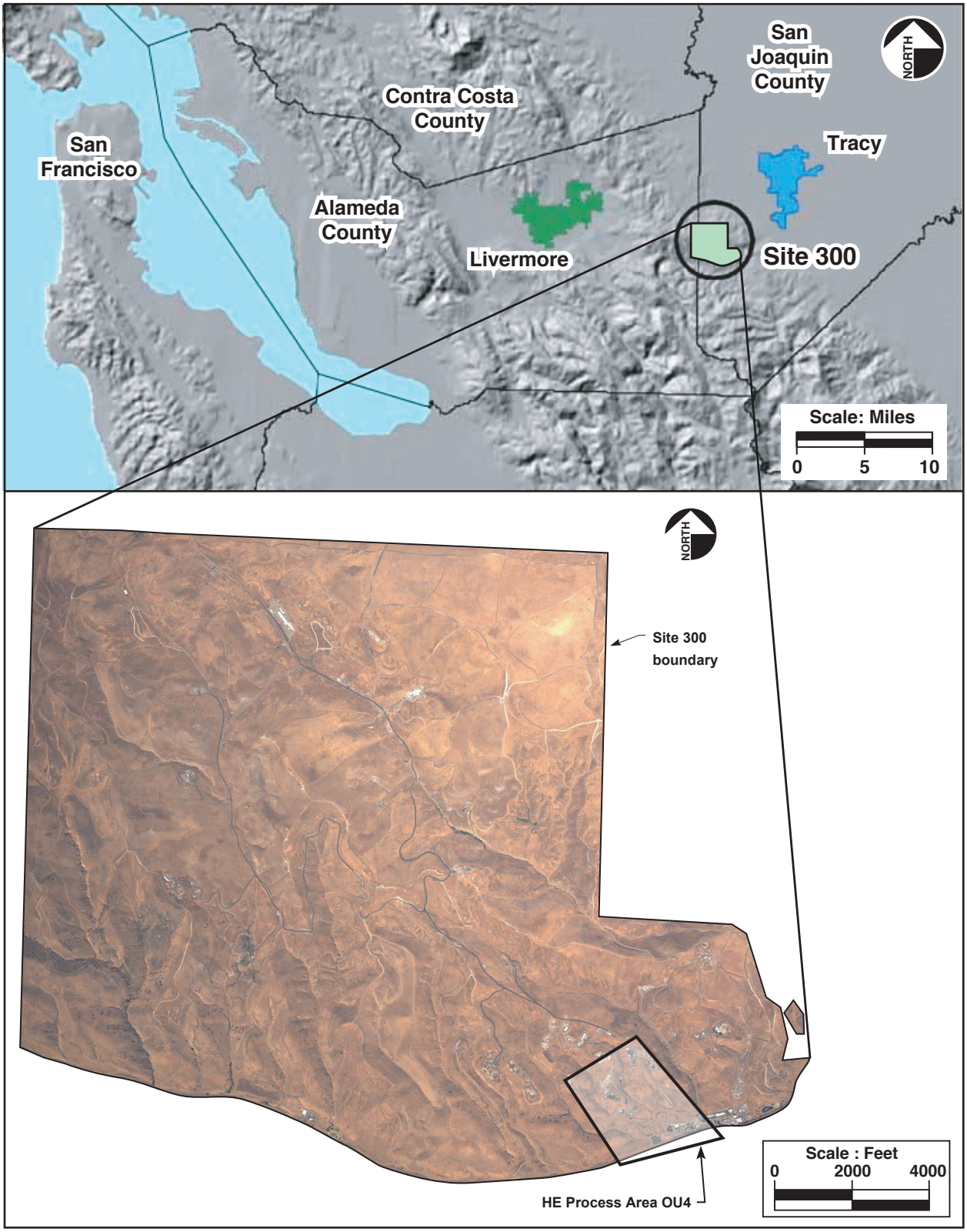

ERD-S3R-11-0164

Figure 1. Location of LLNL Site 300 and the High Explosives (HE) Process Area Operable Unit.

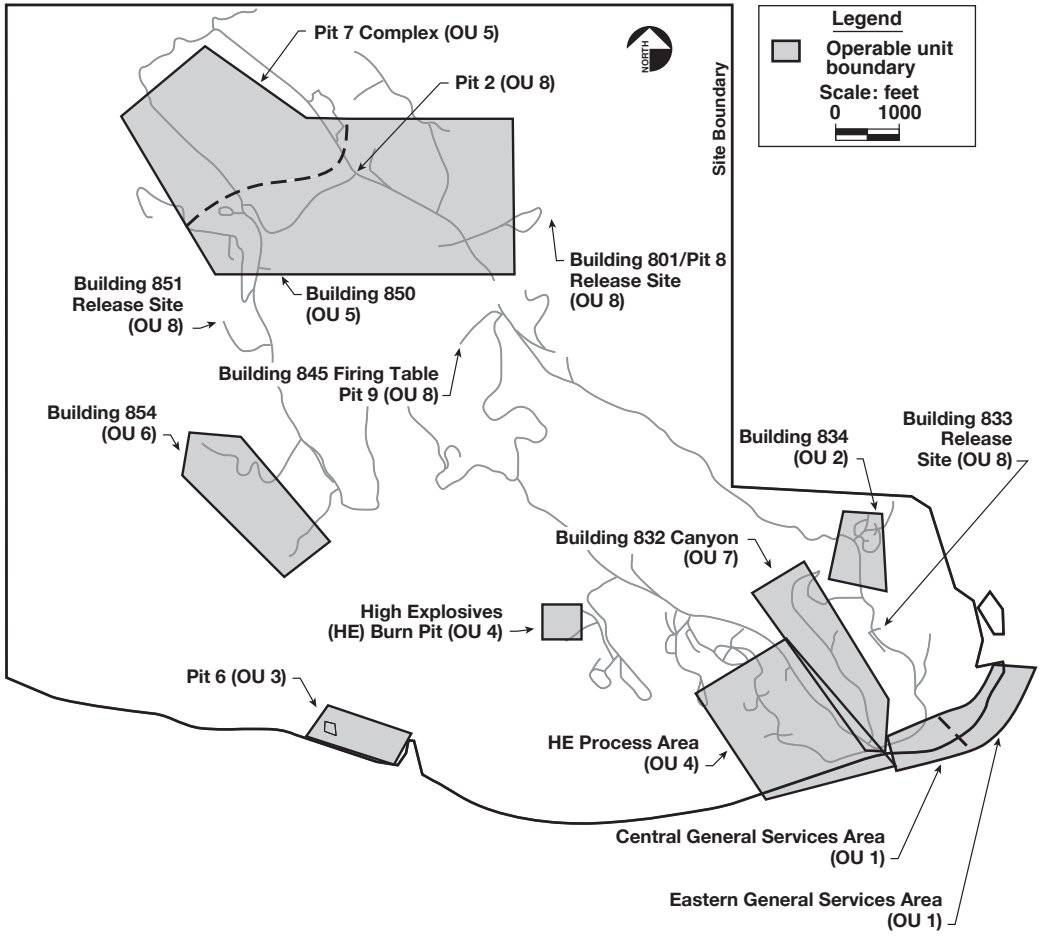

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Figure 2. Site 300 map showing Operable Unit locations.

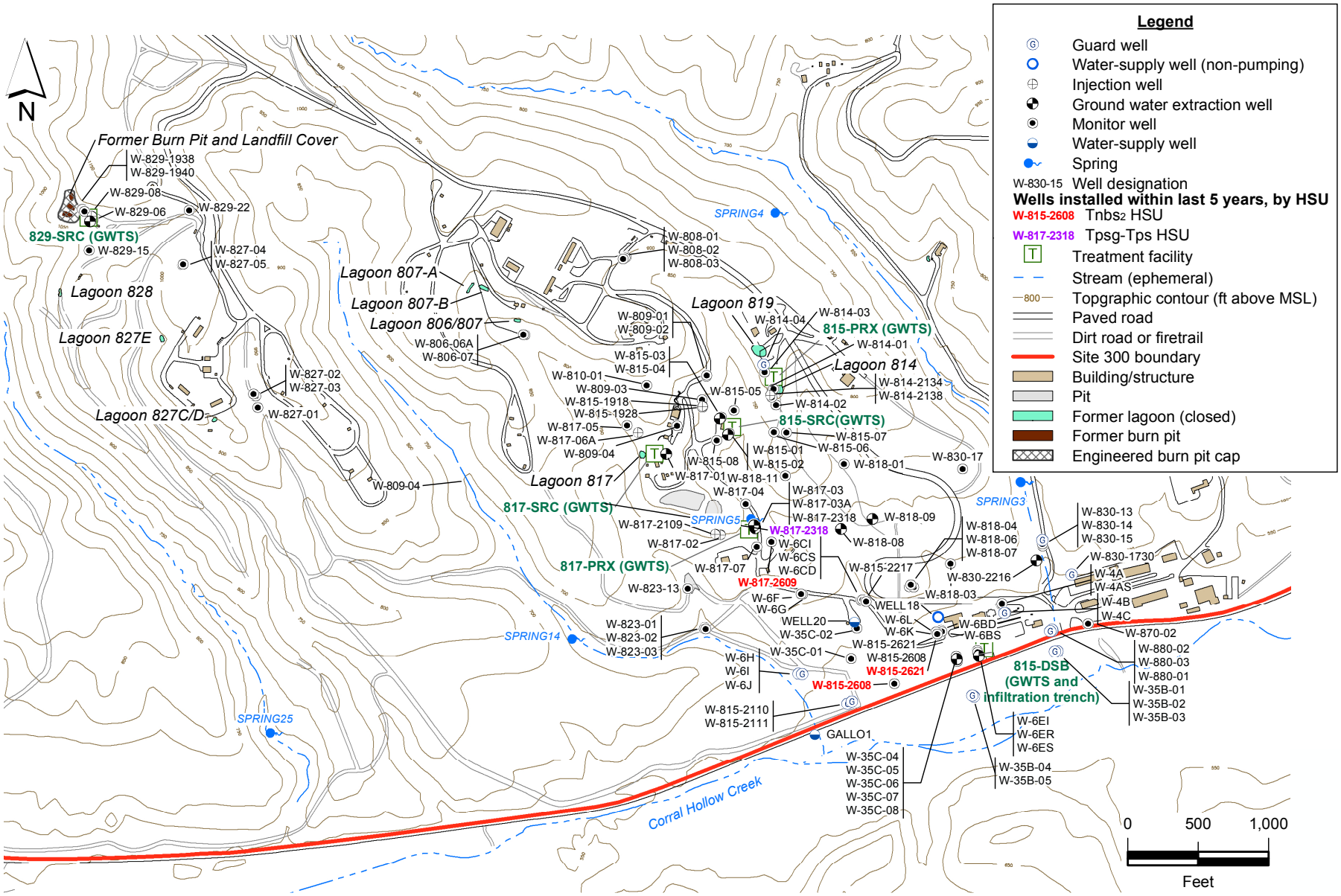

Figure 3. Site map showing monitor, extraction, injection and water-supply wells, and treatment facilities.

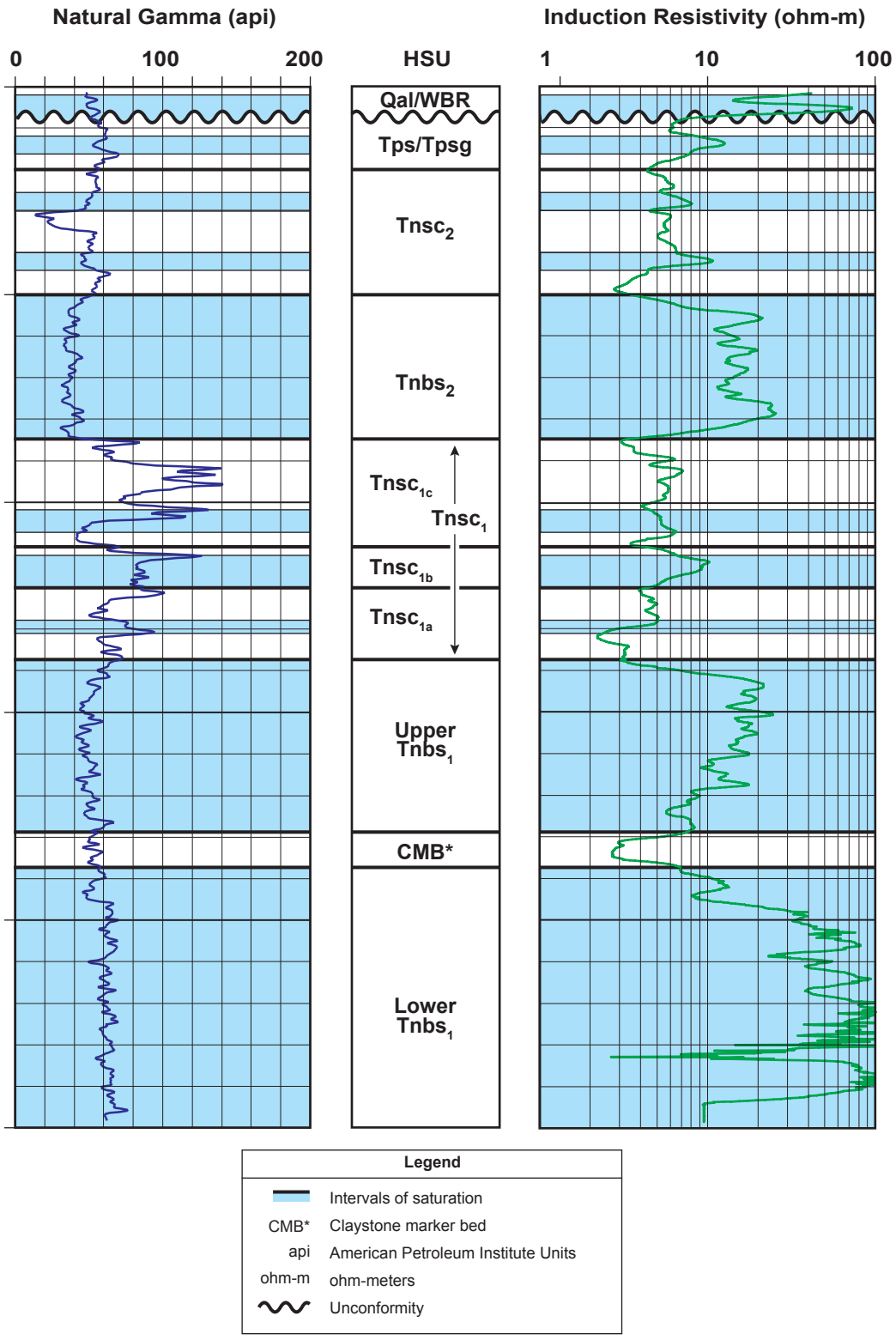

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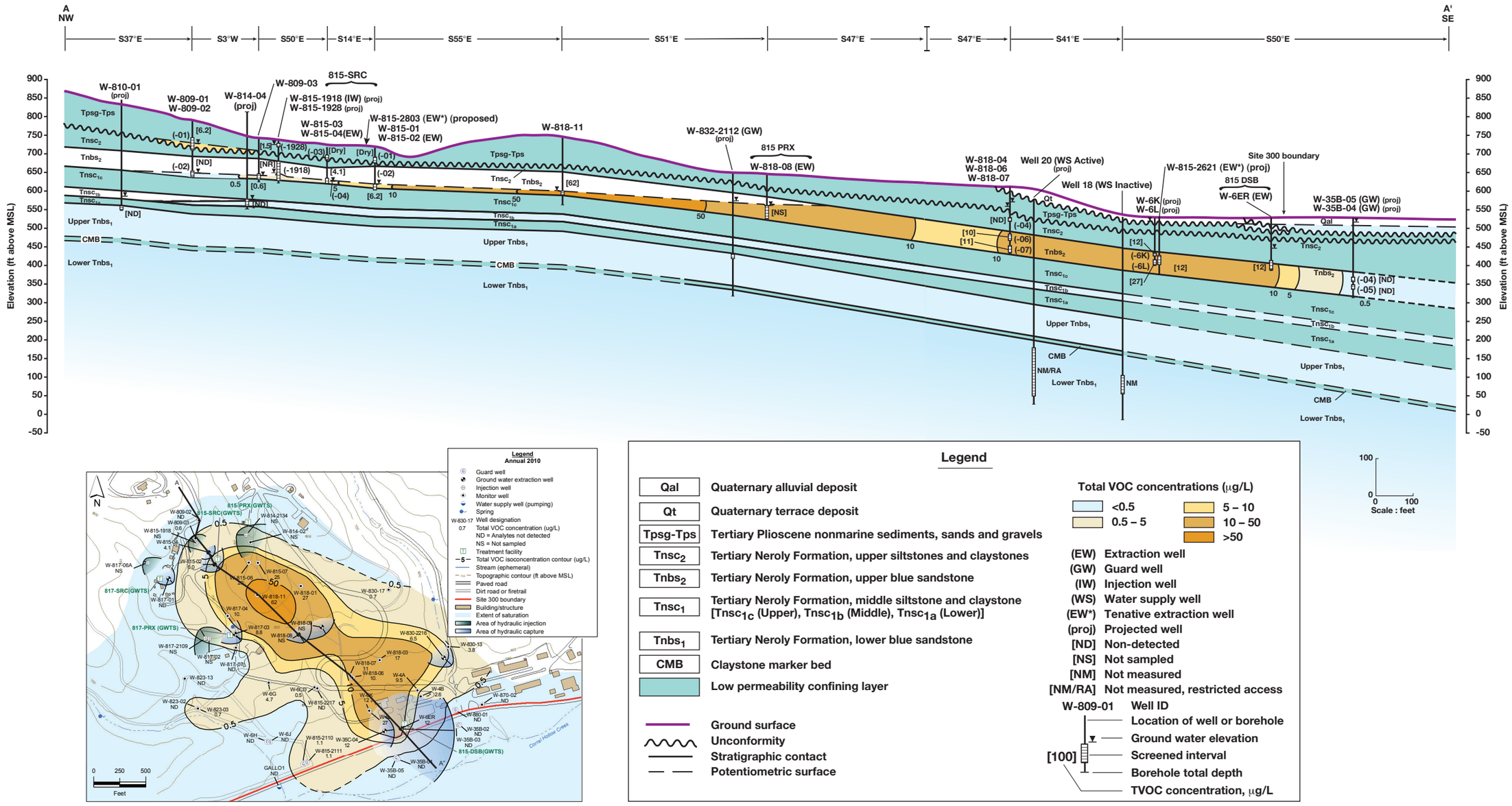
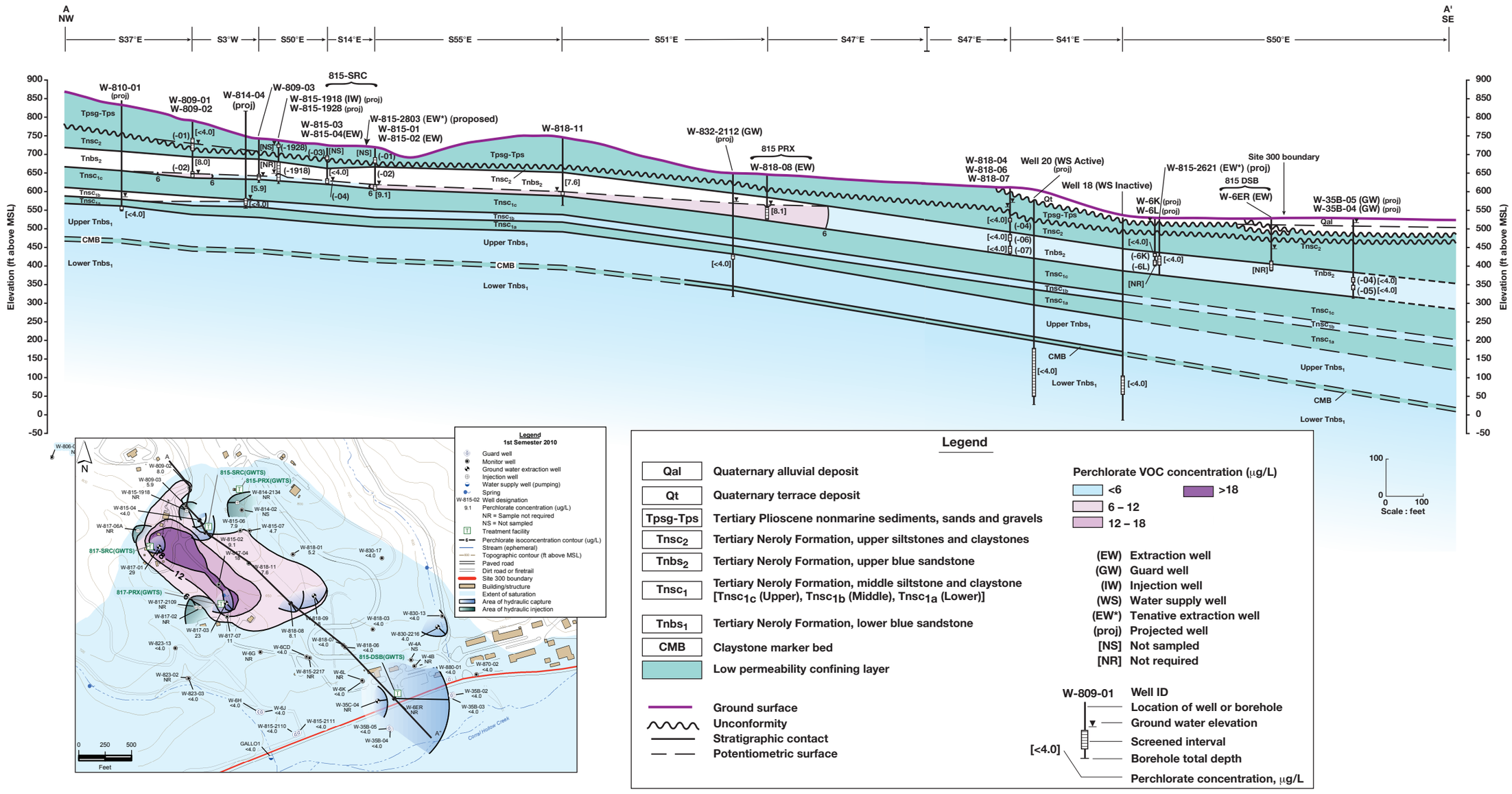
Figure 4. Summary of stratigraphy and hydrostratigraphy.



ERD-S3R-11-0167

Figure 5. Hydrogeologic Cross-section A-A' showing total VOC concentrations.



Legend
1st Semester 2010

- Guard well
- Monitor well
- Ground water extraction well
- Injection well
- Water supply well (pumping)
- Spring
- W-815-02 Well designation
- 9.1 Perchlorate concentration (ug/L)
- NR = Sample not required
- NS = Not sampled
- Treatment facility
- Perchlorate isoconcentration contour (ug/L)
- Stream (ephemeral)
- Topographic contour (ft above MSL)
- Paved road
- Dirt road or firetrail
- Site 300 boundary
- Building/structure
- Extent of saturation
- Area of hydraulic capture
- Area of hydraulic injection

Legend

Qal	Quaternary alluvial deposit
Qt	Quaternary terrace deposit
Tpsg-Tps	Tertiary Pliocene nonmarine sediments, sands and gravels
$Tnsc_2$	Tertiary Neroly Formation, upper siltstones and claystones
$Tnbs_2$	Tertiary Neroly Formation, upper blue sandstone
$Tnsc_1$	Tertiary Neroly Formation, middle siltstone and claystone [$Tnsc_{1c}$ (Upper), $Tnsc_{1b}$ (Middle), $Tnsc_{1a}$ (Lower)]
$Tnbs_1$	Tertiary Neroly Formation, lower blue sandstone
CMB	Claystone marker bed
	Low permeability confining layer

Ground surface
Unconformity
Stratigraphic contact
Potentiometric surface

Perchlorate VOC concentration (µg/L)

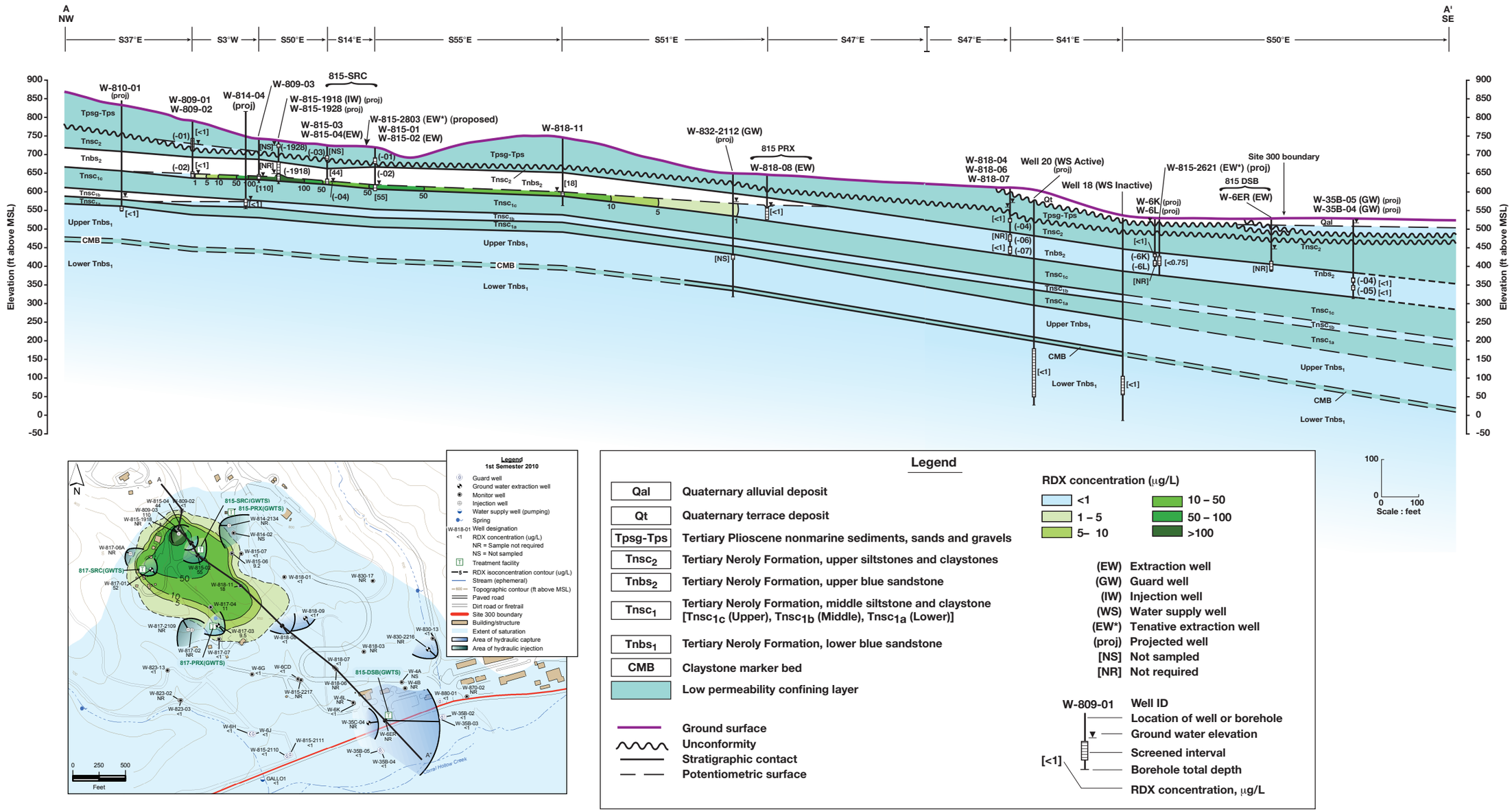
- <6
- 6 – 12
- 12 – 18
- >18

(EW) Extraction well
(GW) Guard well
(IW) Injection well
(WS) Water supply well
(EW*) Tenative extraction well
(proj) Projected well
[NS] Not sampled
[NR] Not required

W-809-01 Well ID
Location of well or borehole
Ground water elevation
Screened interval
Borehole total depth
[<4.0] Perchlorate concentration, µg/L

ERD-S3R-11-0168

Figure 6. Hydrogeologic Cross-section A-A' showing Perchlorate Concentrations.



Legend
1st Semester 2010

- Guard well
- Ground water extraction well
- Monitor well
- Injection well
- Water supply well (pumping)
- Spring
- W-818-01 Well designation
- <1 RDX concentration (ug/L)
- NR = Sample not required
- NS = Not sampled
- Treatment facility
- 5 RDX isoconcentration contour (ug/L)
- Stream (ephemeral)
- 600 Topographic contour (ft above MSL)
- Paved road
- Dirt road or firetrail
- Site 300 boundary
- Building/structure
- Extent of saturation
- Area of hydraulic capture
- Area of hydraulic injection

Legend

Qal	Quaternary alluvial deposit
Qt	Quaternary terrace deposit
Tpsg-Tps	Tertiary Plioscene nonmarine sediments, sands and gravels
$Tnsc_2$	Tertiary Neroly Formation, upper siltstones and claystones
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$Tnbs_1$	Tertiary Neroly Formation, lower blue sandstone
CMB	Claystone marker bed
	Low permeability confining layer

Ground surface
Unconformity
Stratigraphic contact
Potentiometric surface

RDX concentration (µg/L)

<1	10 – 50
1 – 5	50 – 100
5– 10	>100

(EW) Extraction well
(GW) Guard well
(IW) Injection well
(WS) Water supply well
(EW*) Tenative extraction well
(proj) Projected well
[NS] Not sampled
[NR] Not required

W-809-01 Well ID
Location of well or borehole
Ground water elevation
Screened interval
Borehole total depth
[<1] RDX concentration, µg/L

100
0
0 100
Scale : feet

ERD-S3R-11-0169

Figure 7. Hydrogeologic Cross-section A-A' showing RDX concentrations.

Building 829
Open Burn Pit

Building 806/807
Lagoon

Building 810
Dry Well

Building 814
Dry Well

Building 817
Lagoon

Building 815
Hard Stand

Route 2

Route 3

G

Site boundary

Corral Hollow Road

Contaminated subsurface soil/rock

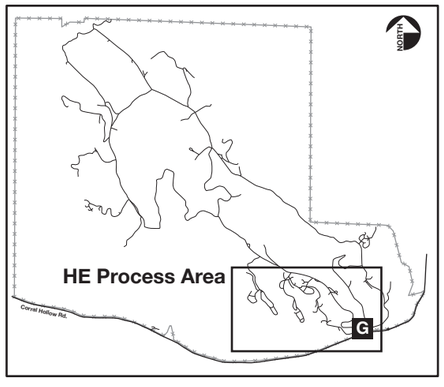
- Control excavation activities

Contaminated ground water

- Prevent water-supply use/consumption
- Prohibit water-supply well drilling

General

- Maintain access restrictions (i.e., fencing, security controls)
- Prohibit transfer of land with unmitigated contamination



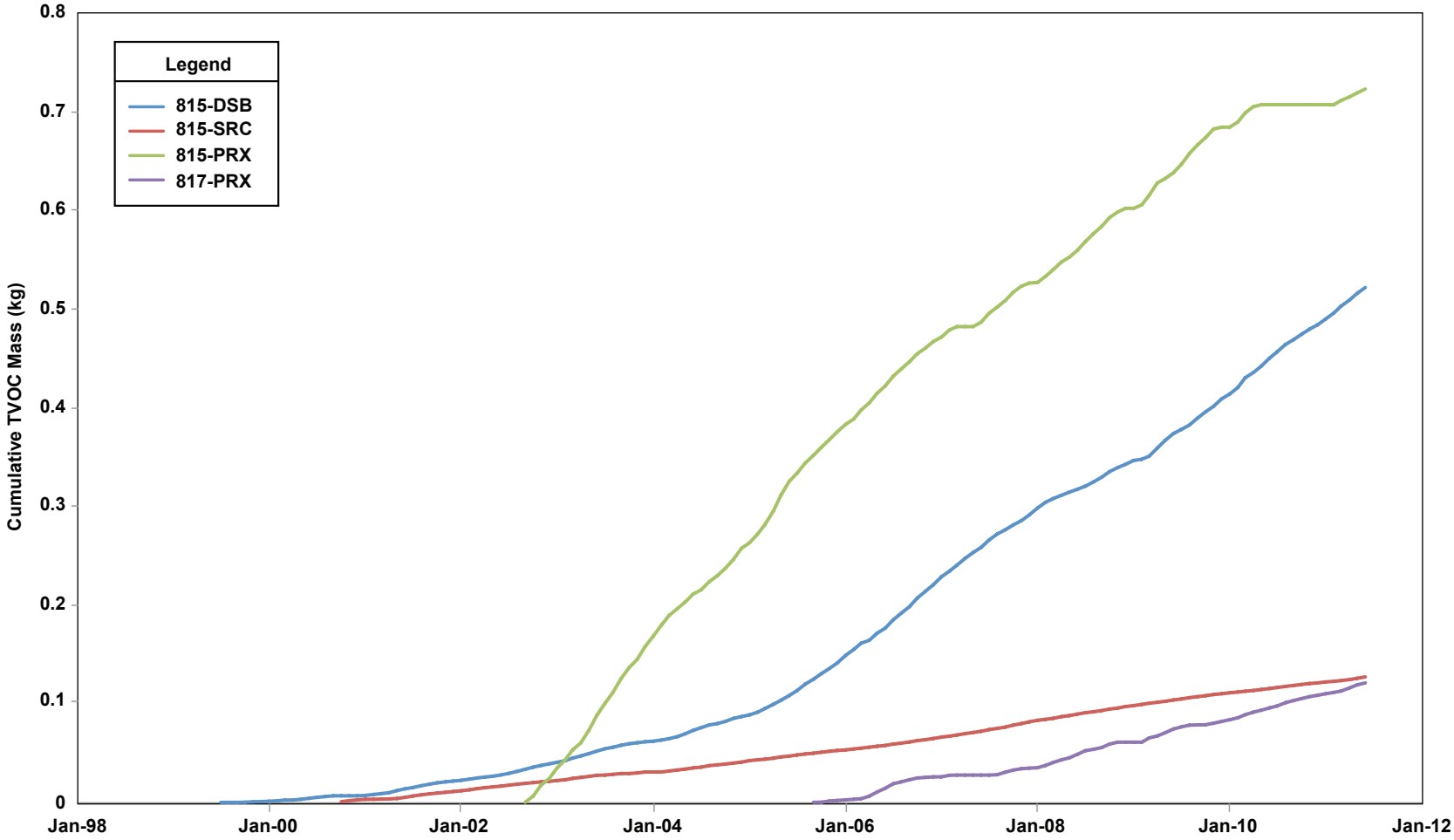
Legend

- Ground water above MCLs
- Site boundary
- Fence
- G Guard gate
- Building
- Road

Scale : Feet
0 400 800

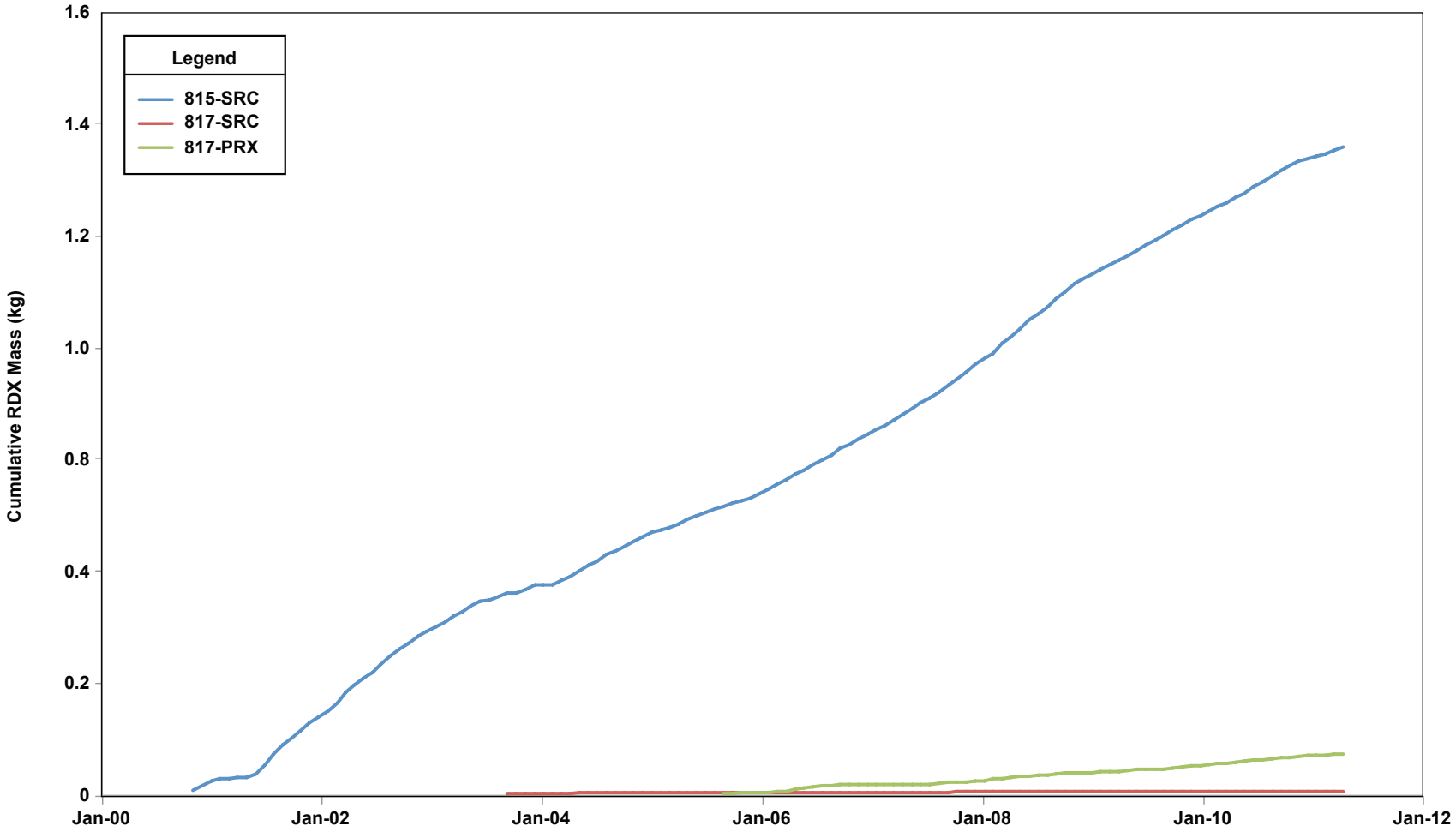
ERD-S3R-11-0170

Figure 8. Institutional/land use controls.



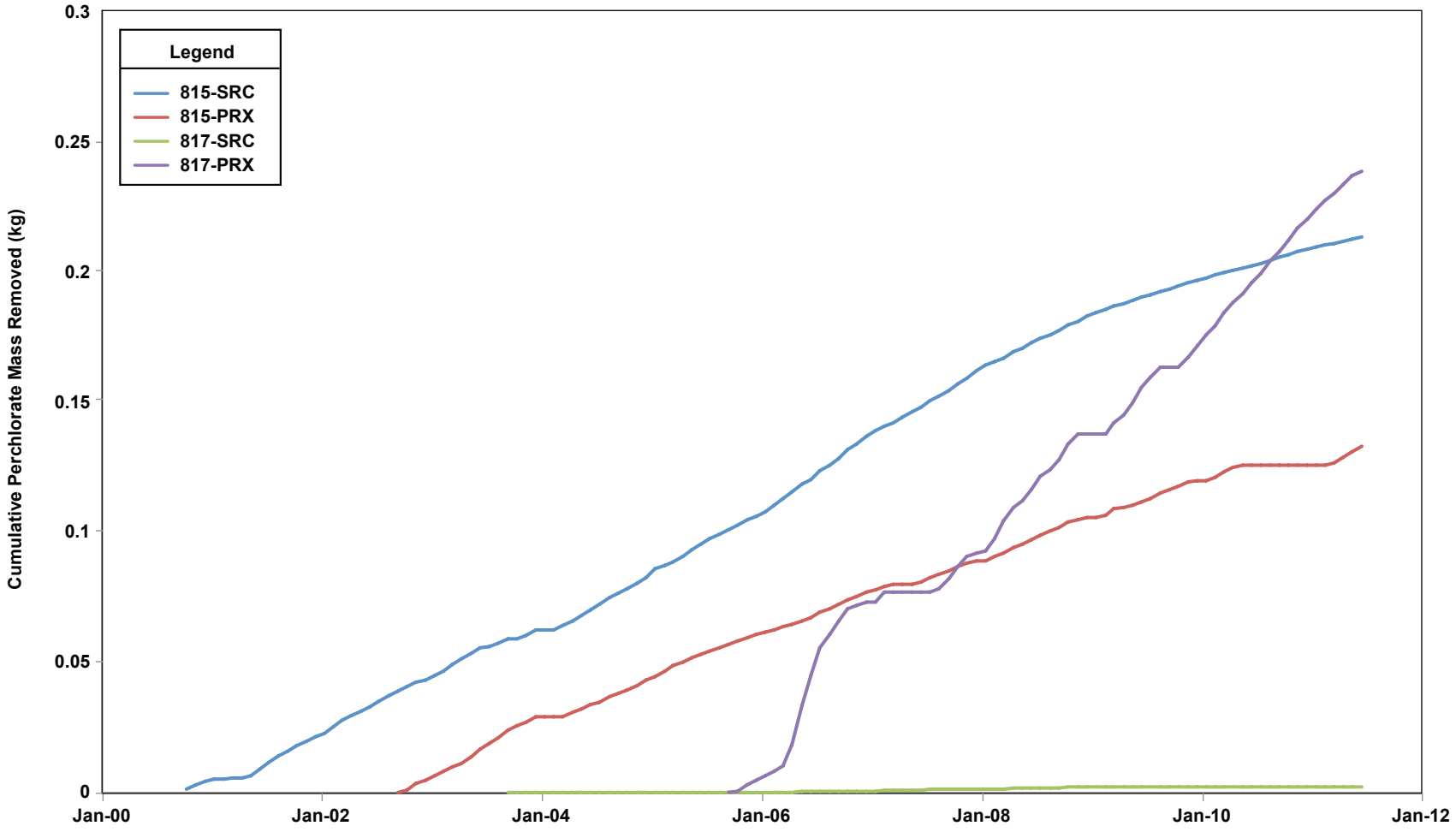
ERD_S3R_11_0172

Figure 9. Time-series plots of cumulative mass of total VOCs removed by ground water extraction per treatment facility.



ERD_S3R_11_0174

Figure 10. Time-series plots of cumulative mass of RDX removed by ground water extraction per treatment facility.



ERD_S3R_11_0175

Figure 11. Time-series plots of cumulative mass of perchlorate removed by ground water extraction per treatment facility.

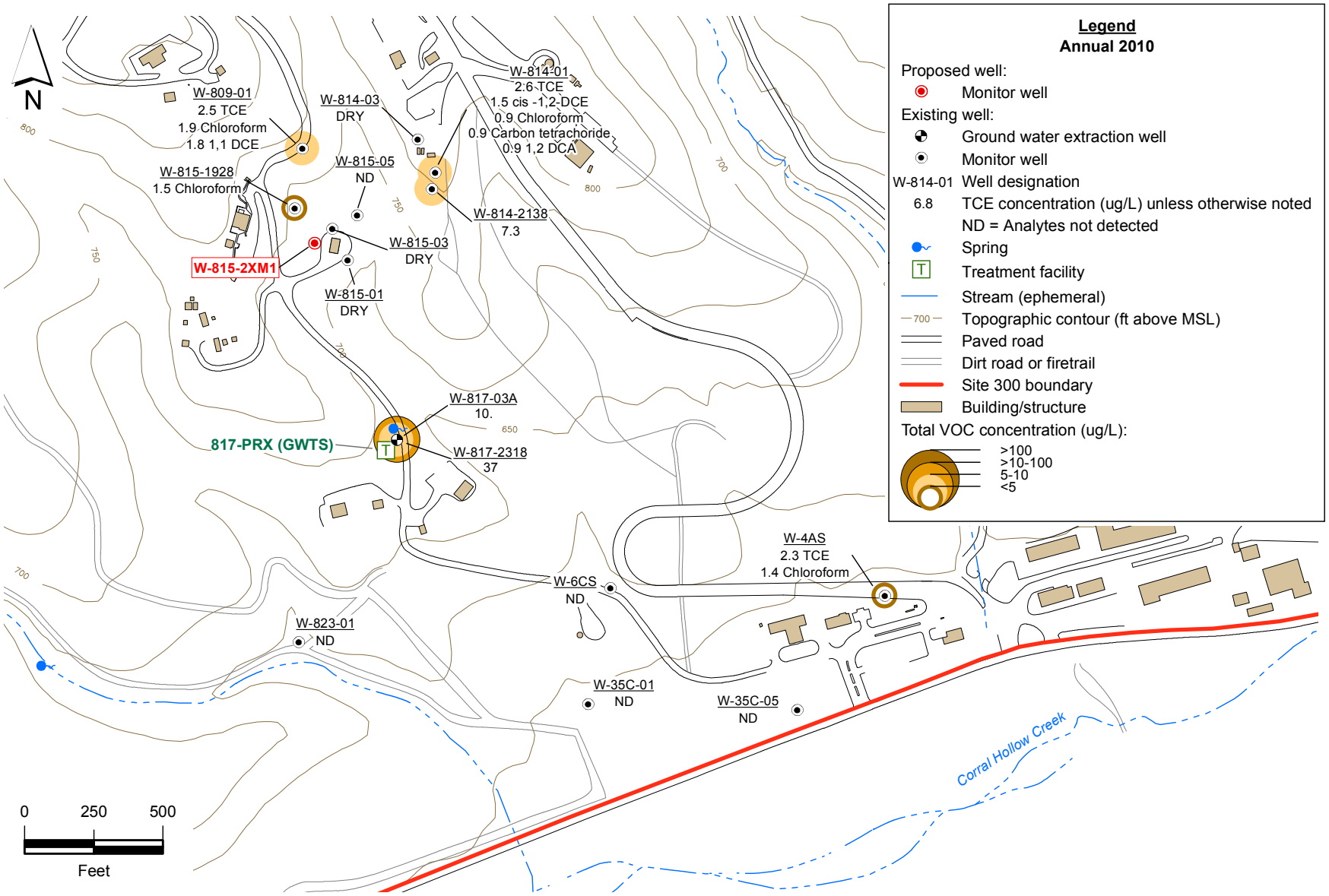


Figure 12. Map showing total VOC concentrations for the Tpsg-Tps hydrostratigraphic unit.

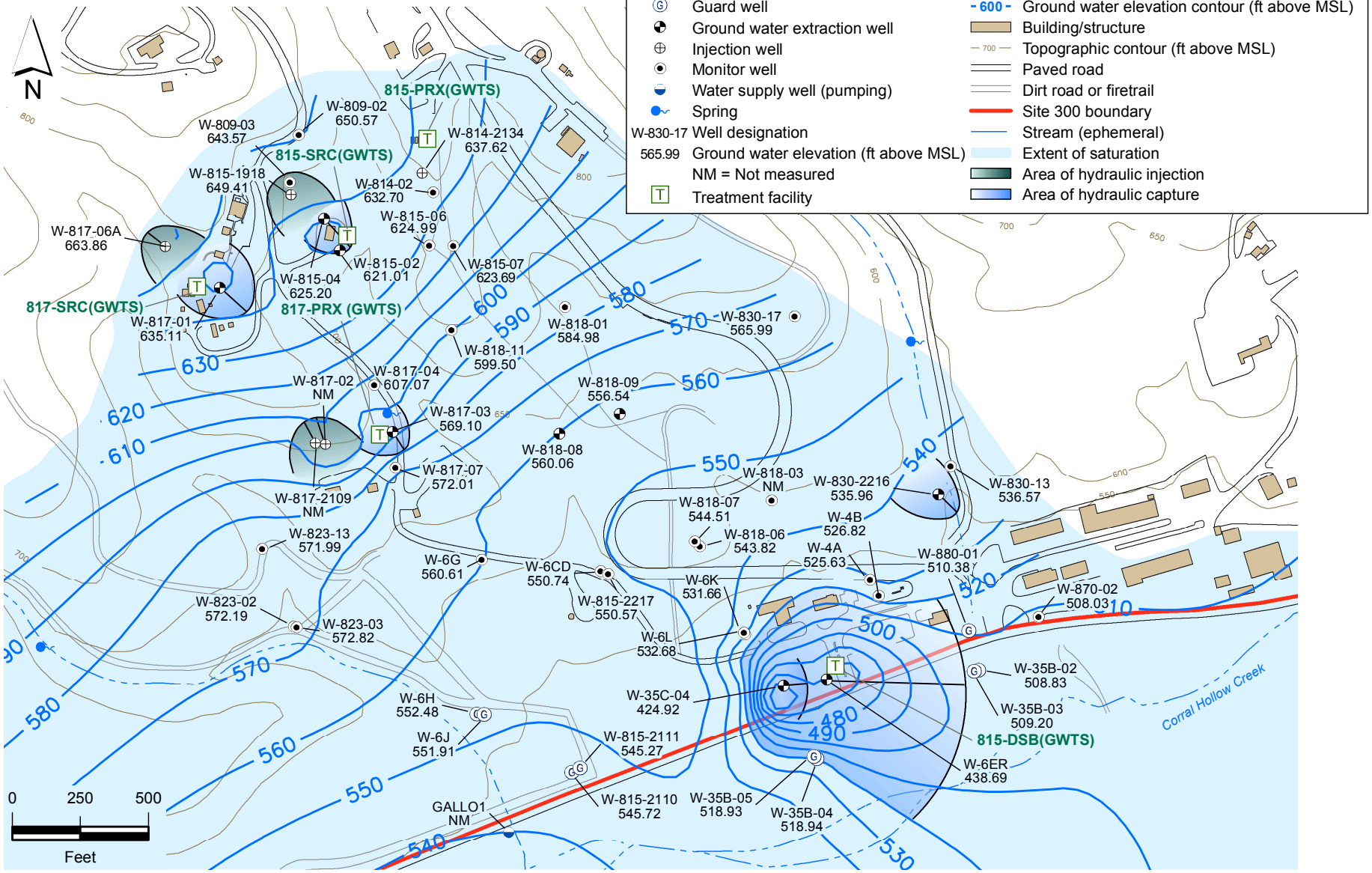


Figure 13. Ground water potentiometric surface map for the $Tnbs_2$ hydrostratigraphic unit, including hydraulic capture zones.

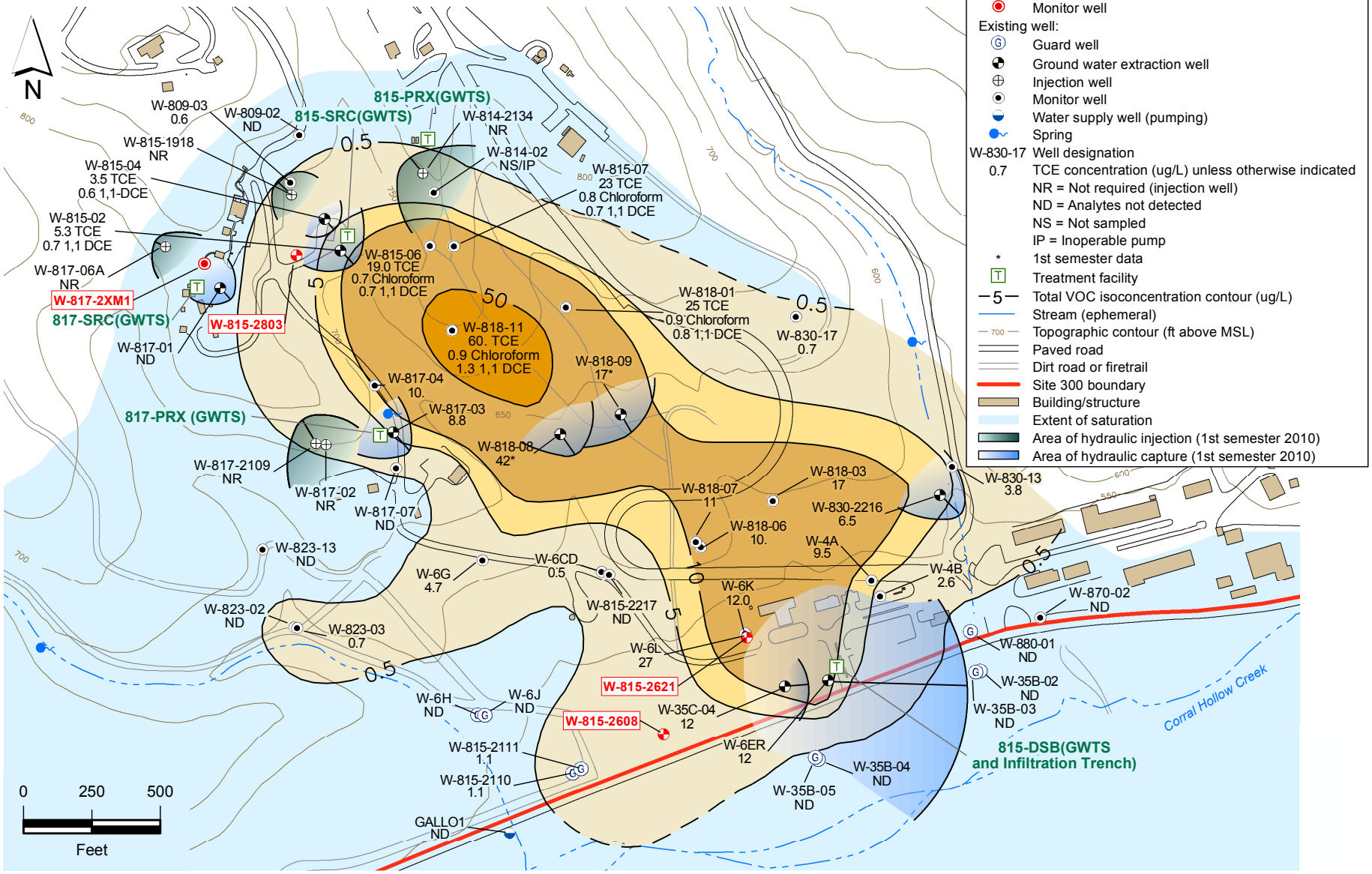


Figure 14. Map showing total VOC isoconcentration contours for the $Tnbs_2$ hydrostratigraphic unit.

ERD_S3R_11_0173

Figure 15. Time-series plots of a) total VOCs, b) RDX, and c) perchlorate in ground water in the Building 815-Source Area extraction wells and monthly facility flow.

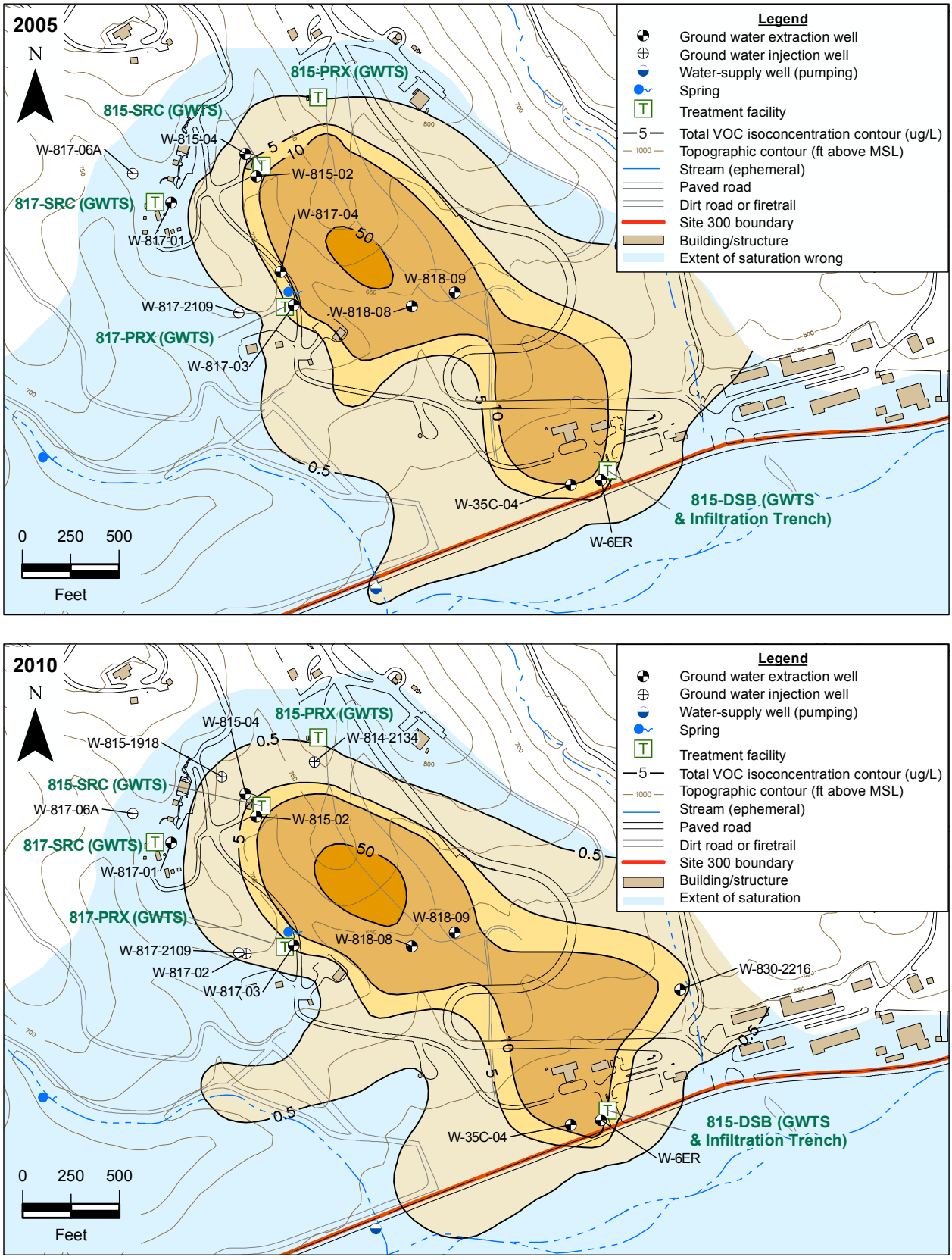
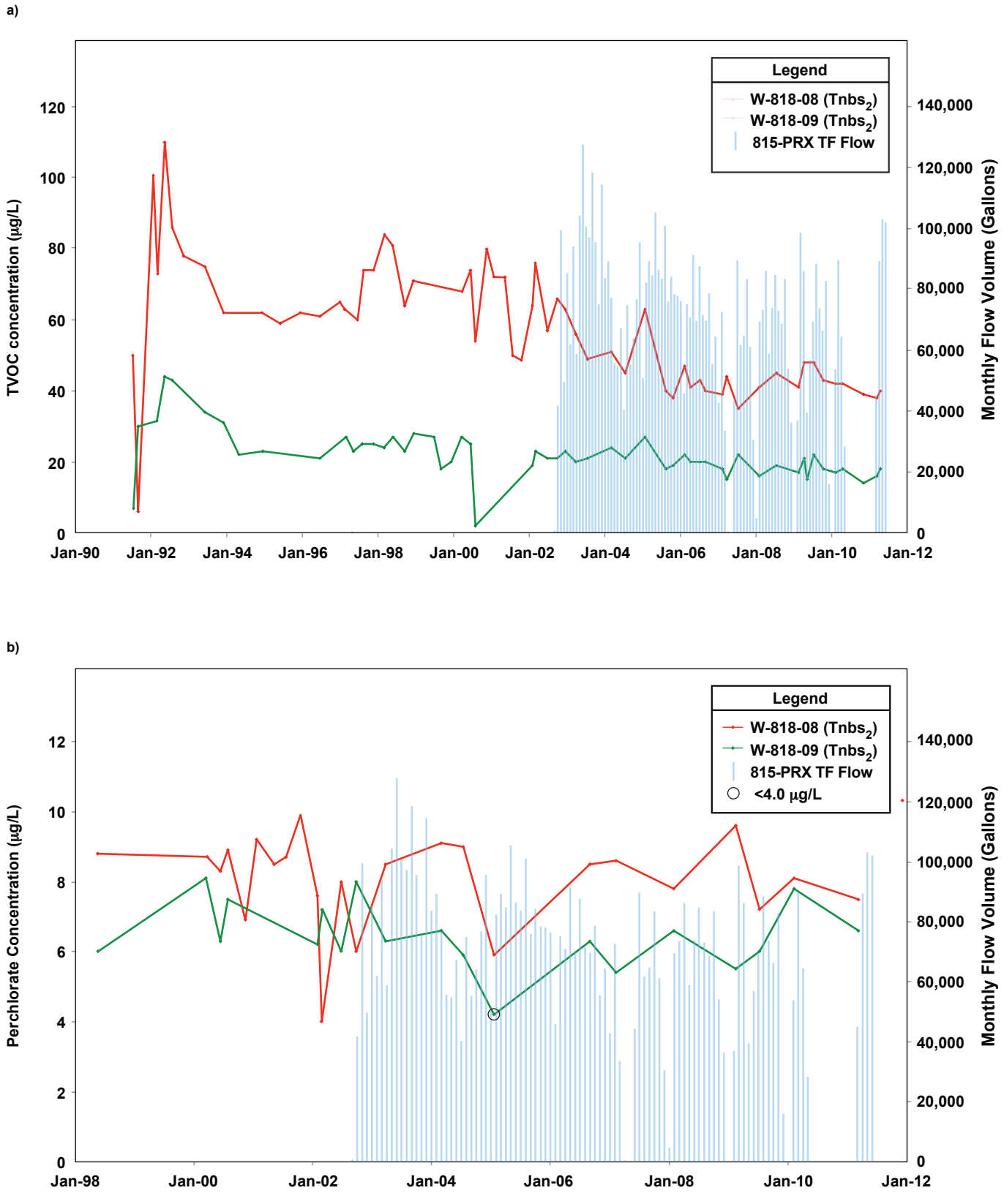
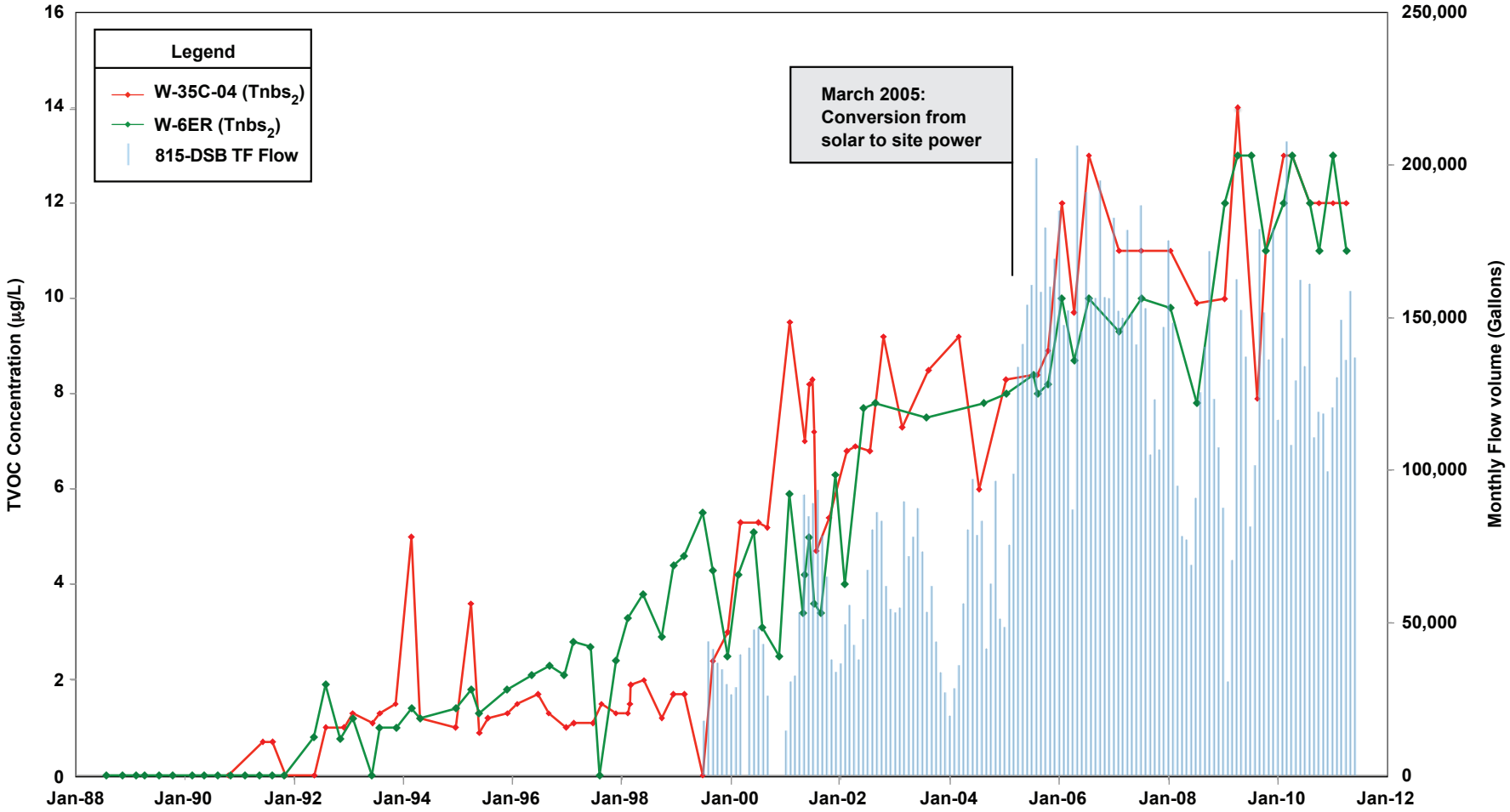


Figure 16. Comparison of the existing extraction wells and the distribution of total VOCs in ground water the $Tnbs_2$ hydrostratigraphic unit in the second semester 2005 and the second semester 2010.



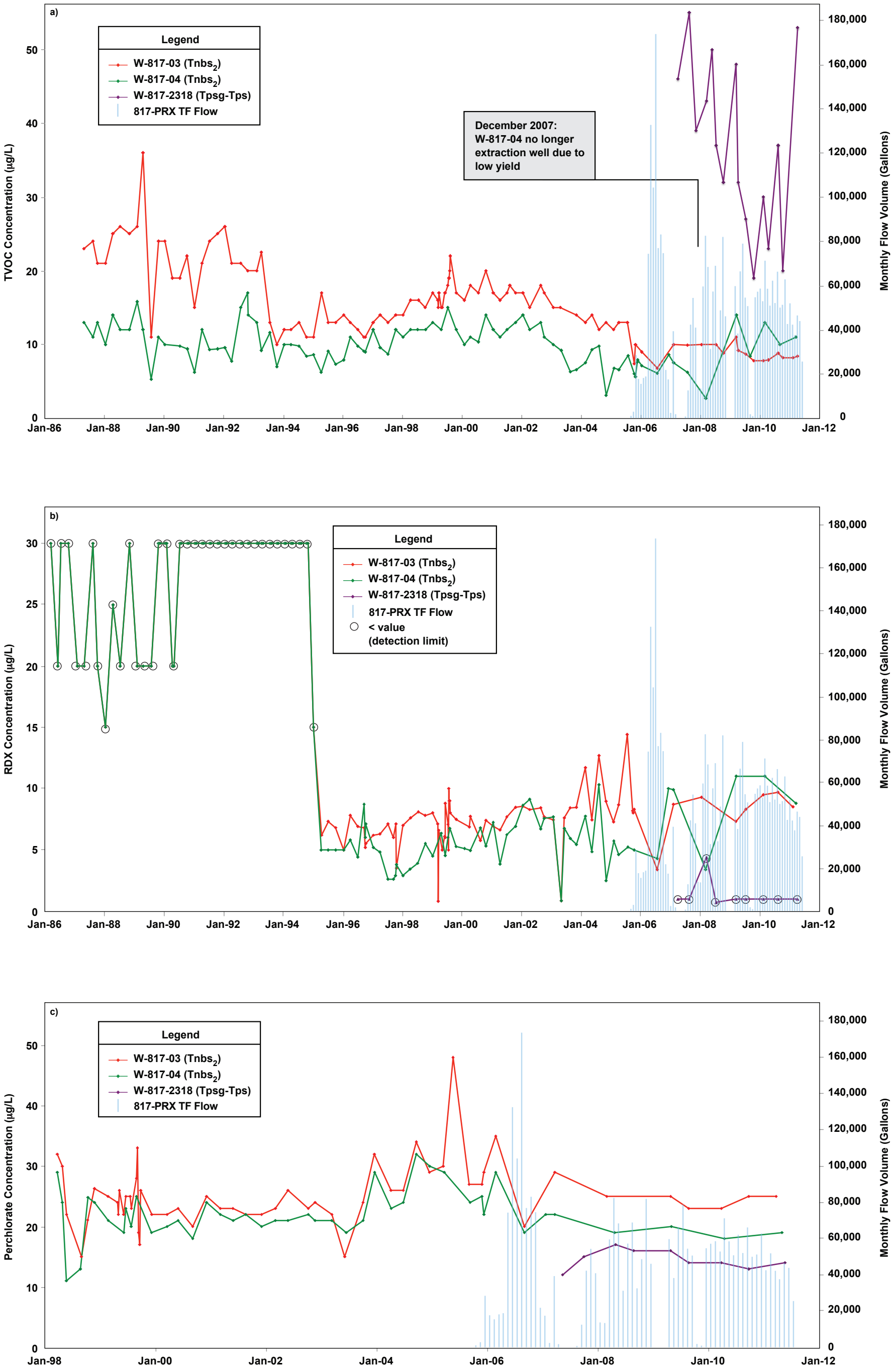
ERD_S3R_11_0176

Figure 17. Time-series plots of a) total VOCs, and b) perchlorate in ground water in the Building 815-Proximal Area extraction wells and monthly facility flow.



ERD_S3R_11_0171

Figure 18. Time-series plots of total VOCs in ground water in the Building 815-Distal Site Boundary Area extraction wells and monthly facility flow.



ERD_S3R_11_0178

Figure 19. Time-series plots of a) total VOCs, b) RDX, and c) perchlorate in ground water in the Building 817-Proximal Area extraction wells and monthly facility flow.

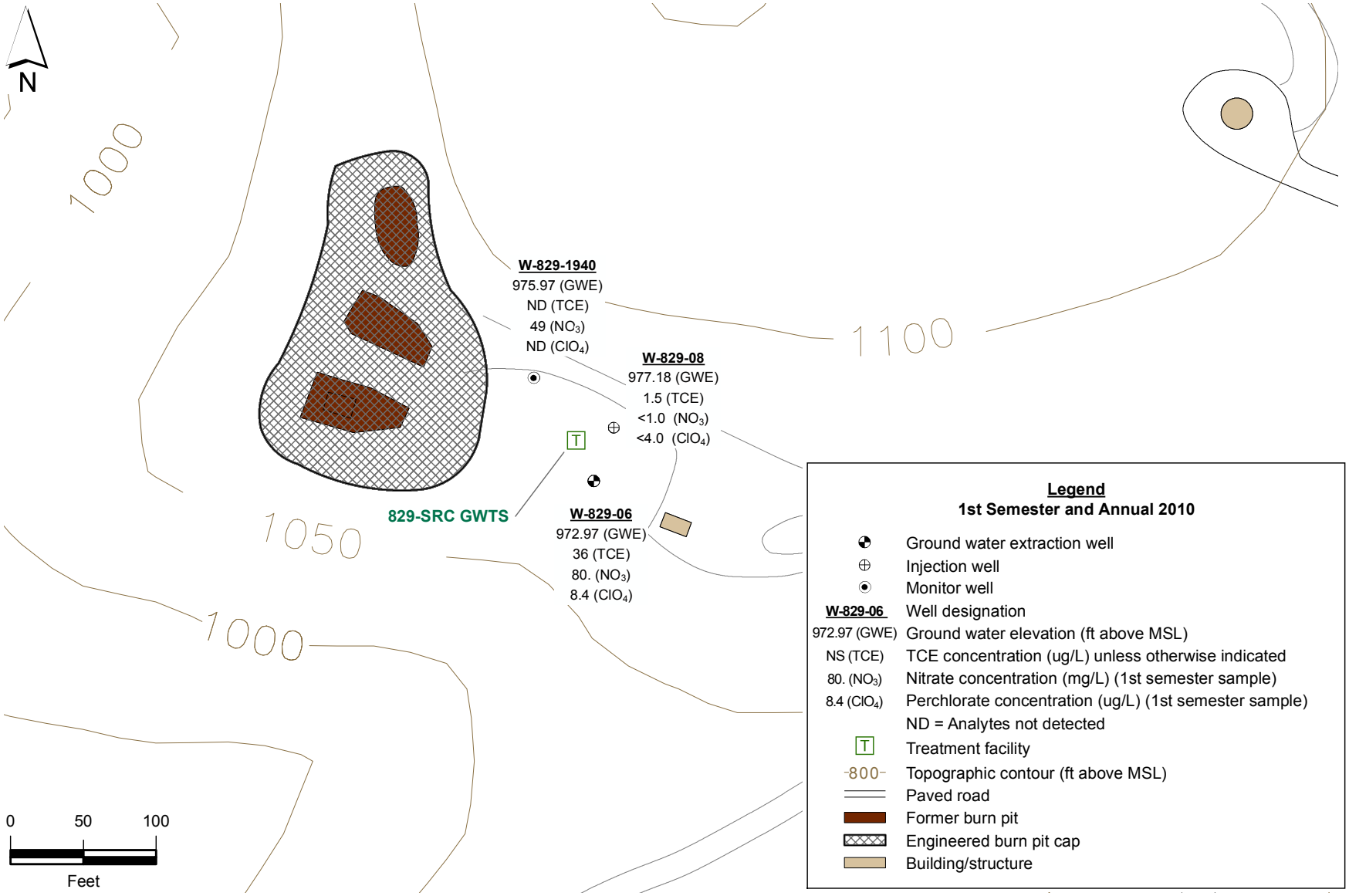
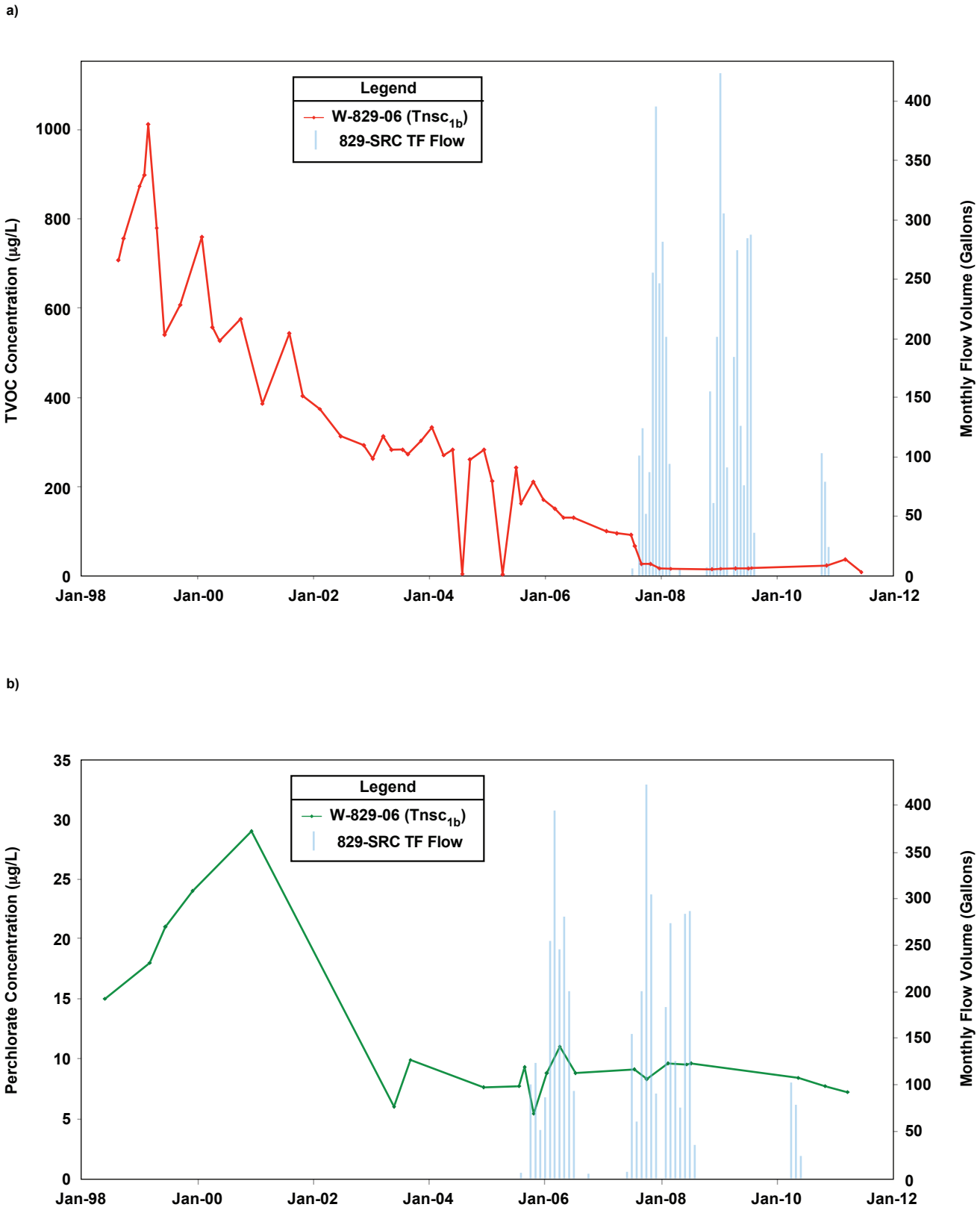


Figure 20. Building 829 burn pit map showing monitor, extraction and injection wells; ground water elevations; and total VOC, perchlorate, and nitrate concentrations for the $Tnsc_{1b}$ hydrostratigraphic unit.



ERD_S3R_11_0179

Figure 21. Time-series plots of a) TVOCs, and b) perchlorate in ground water in the Building 829-Source Area extraction wells and monthly facility flow.

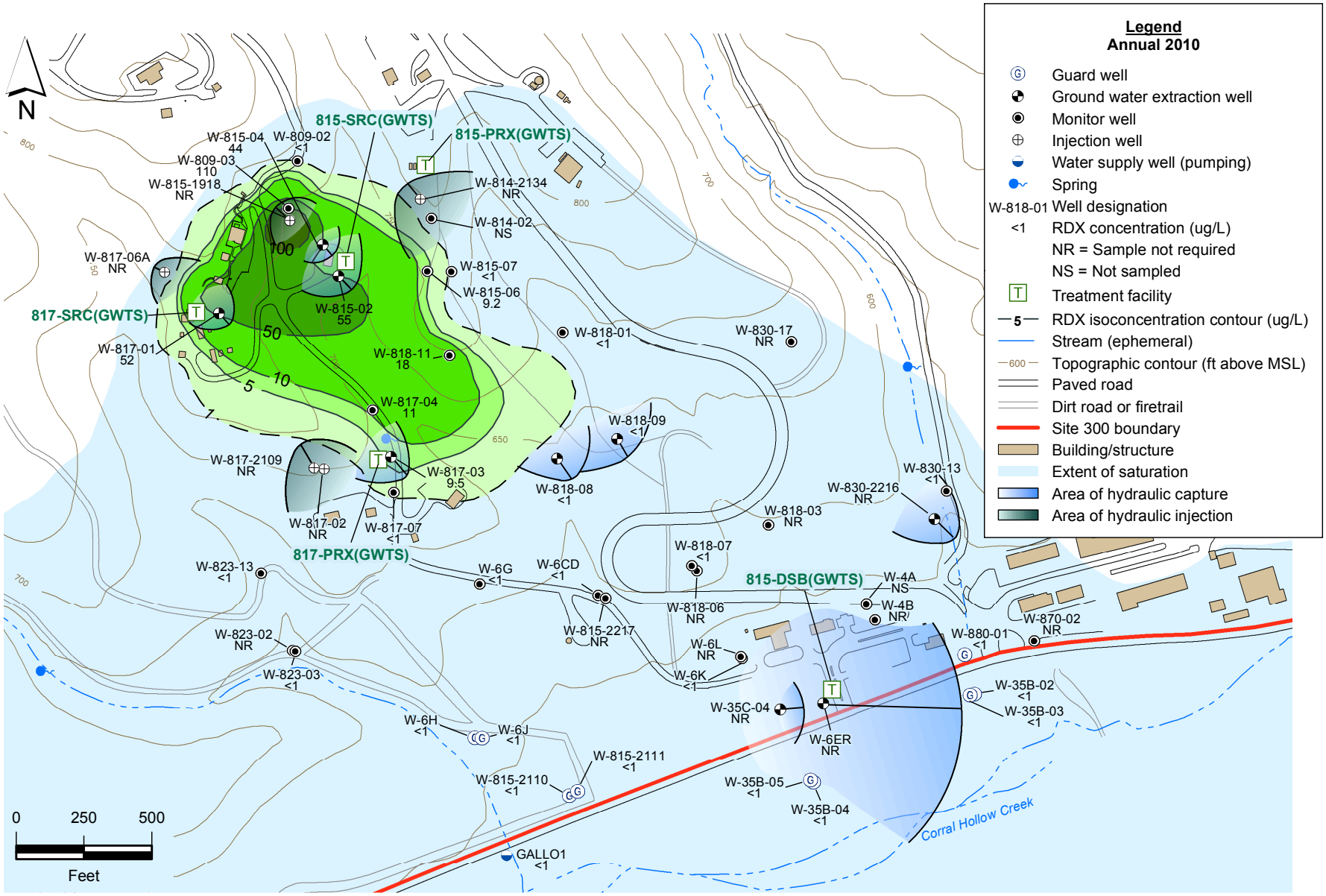


Figure 22. RDX isoconcentration contour map for the $Tnbs_2$ hydrostratigraphic unit.

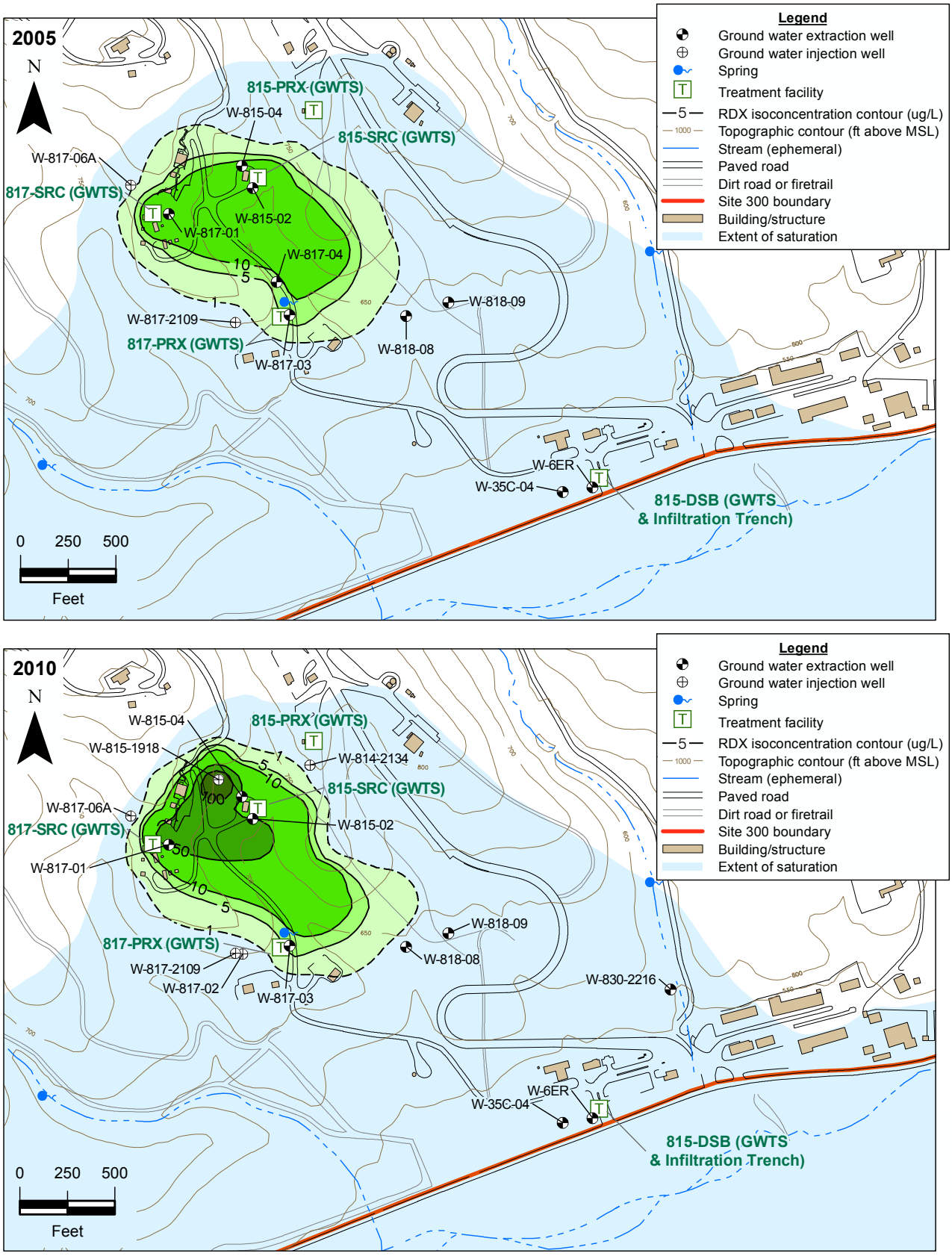
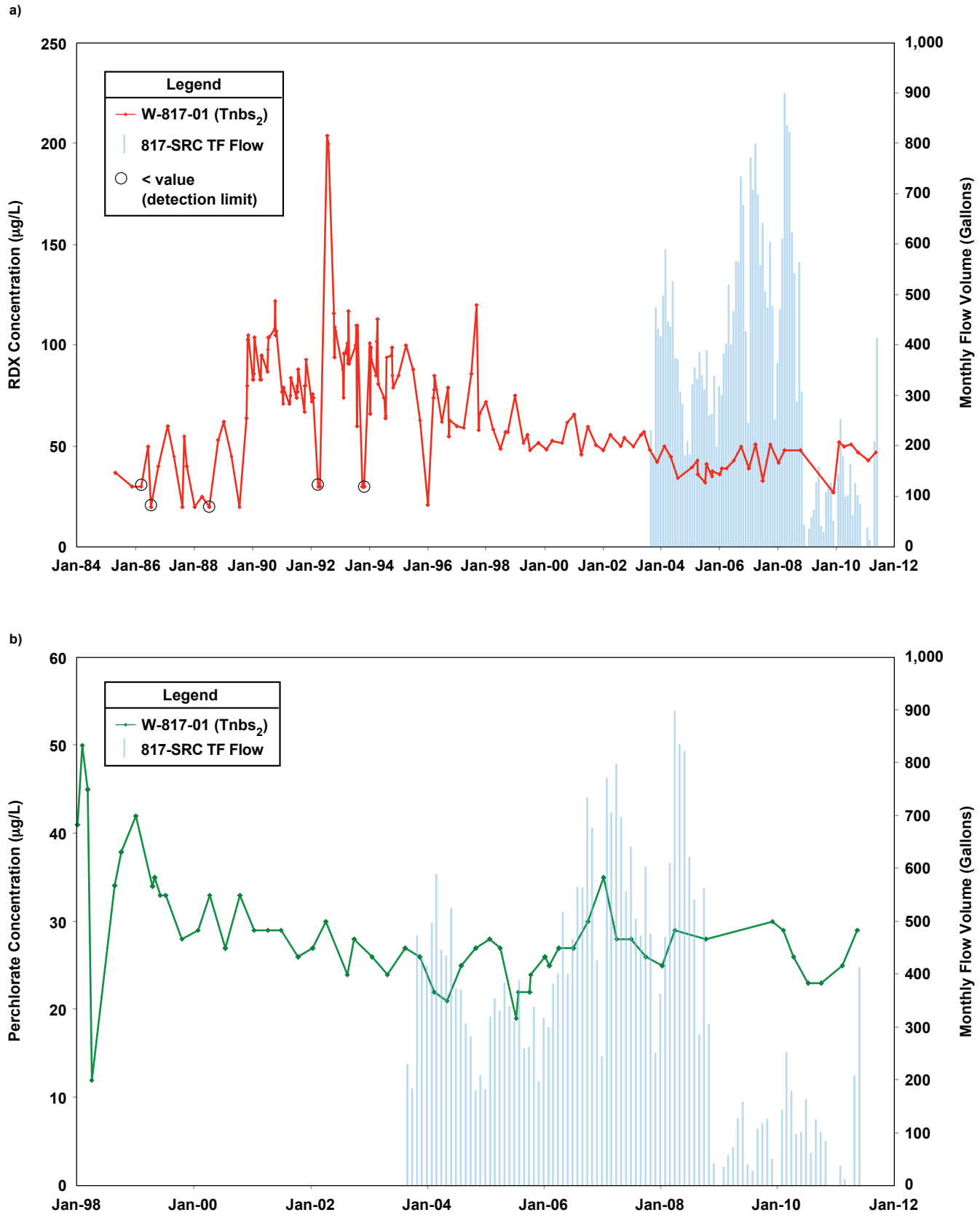


Figure 23. Comparison of the existing extraction wells and the distribution of RDX in ground water in the $Tnbs_2$ hydrostratigraphic unit in the first semester 2005 and the first semester 2010.



ERD_S3R_11_0177

Figure 24. Time-series plots of a) RDX, and b) perchlorate in ground water in the Building 817-Source Area extraction wells and monthly facility flow.

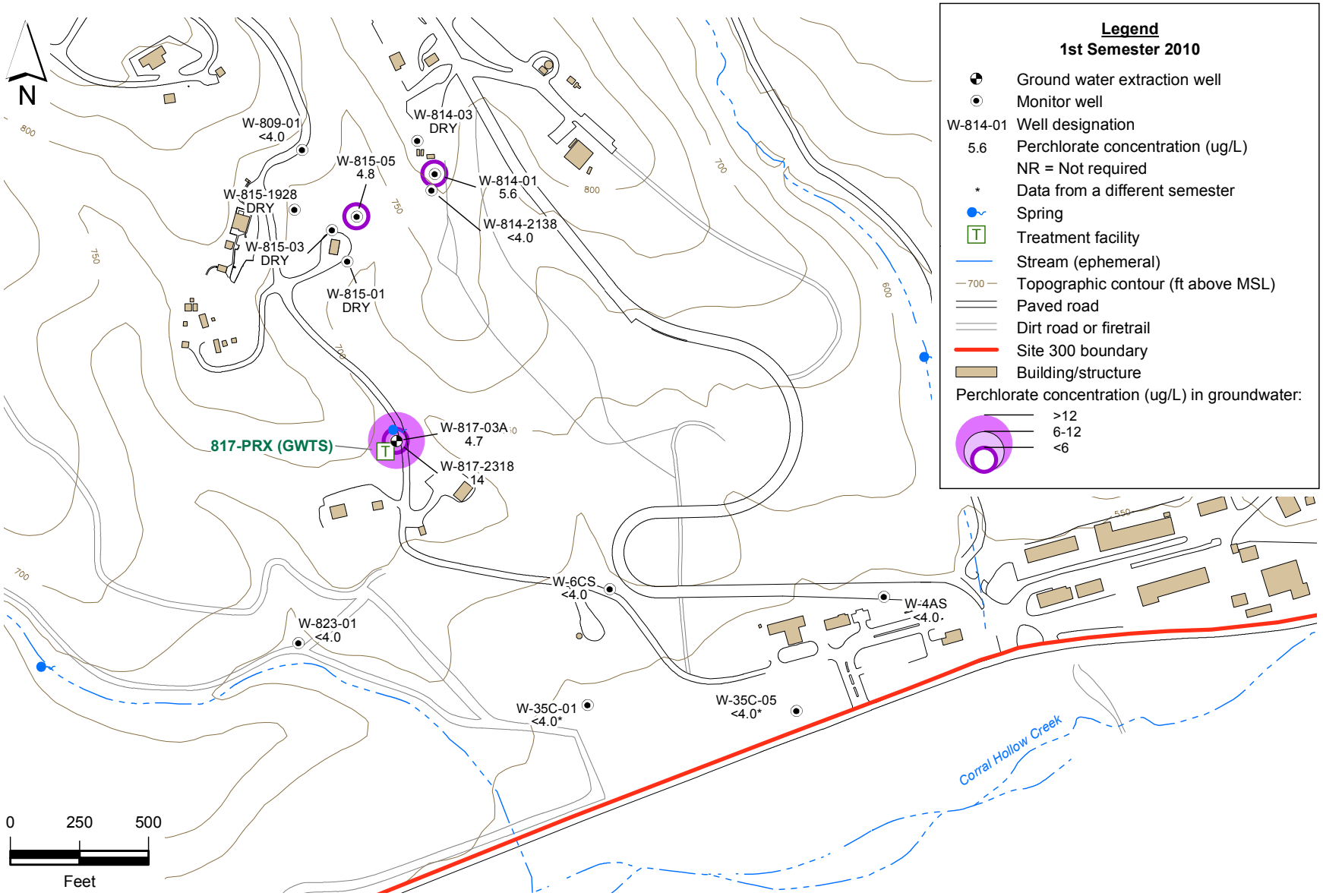


Figure 25. Map showing perchlorate concentrations for the Tpsg-Tps hydrostratigraphic unit.

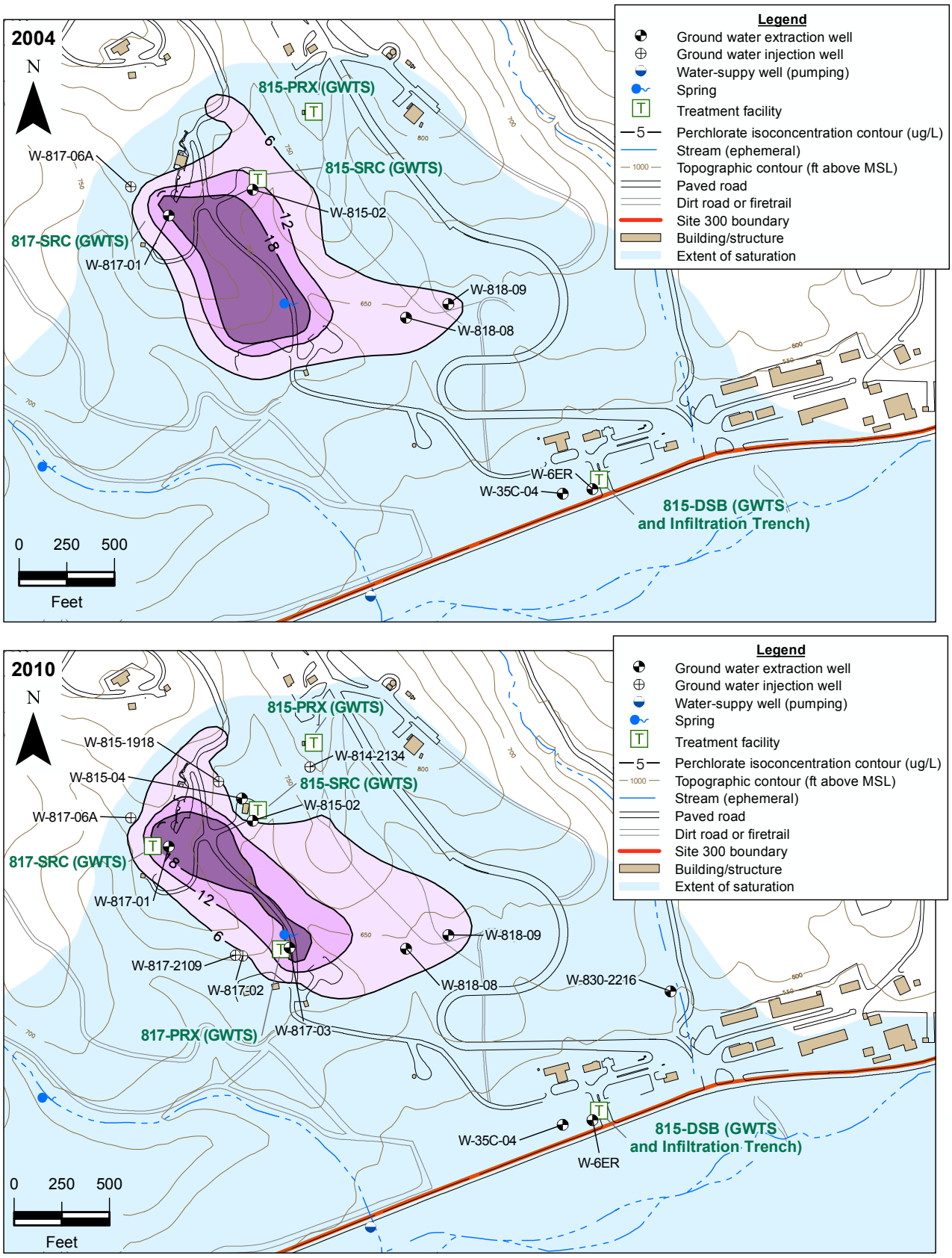


Figure 26. Comparison of the existing extraction wells and the distribution of perchlorate in ground water in the $Tnbs_2$ hydrostratigraphic unit in the second semester 2004 and the first semester 2010.

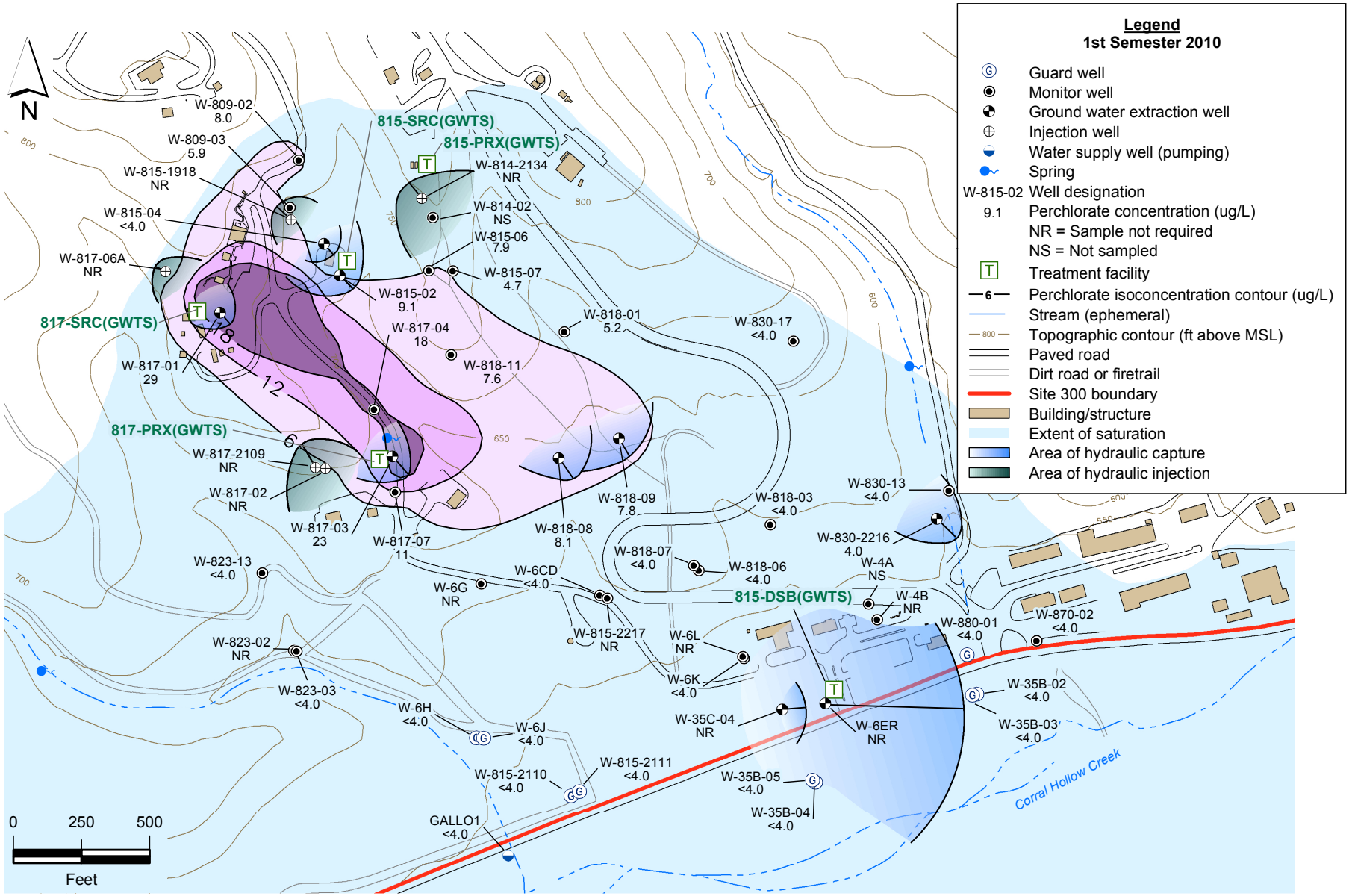


Figure 27. Perchlorate isoconcentration contour map for the Tnbs$_2$ hydrostratigraphic unit.

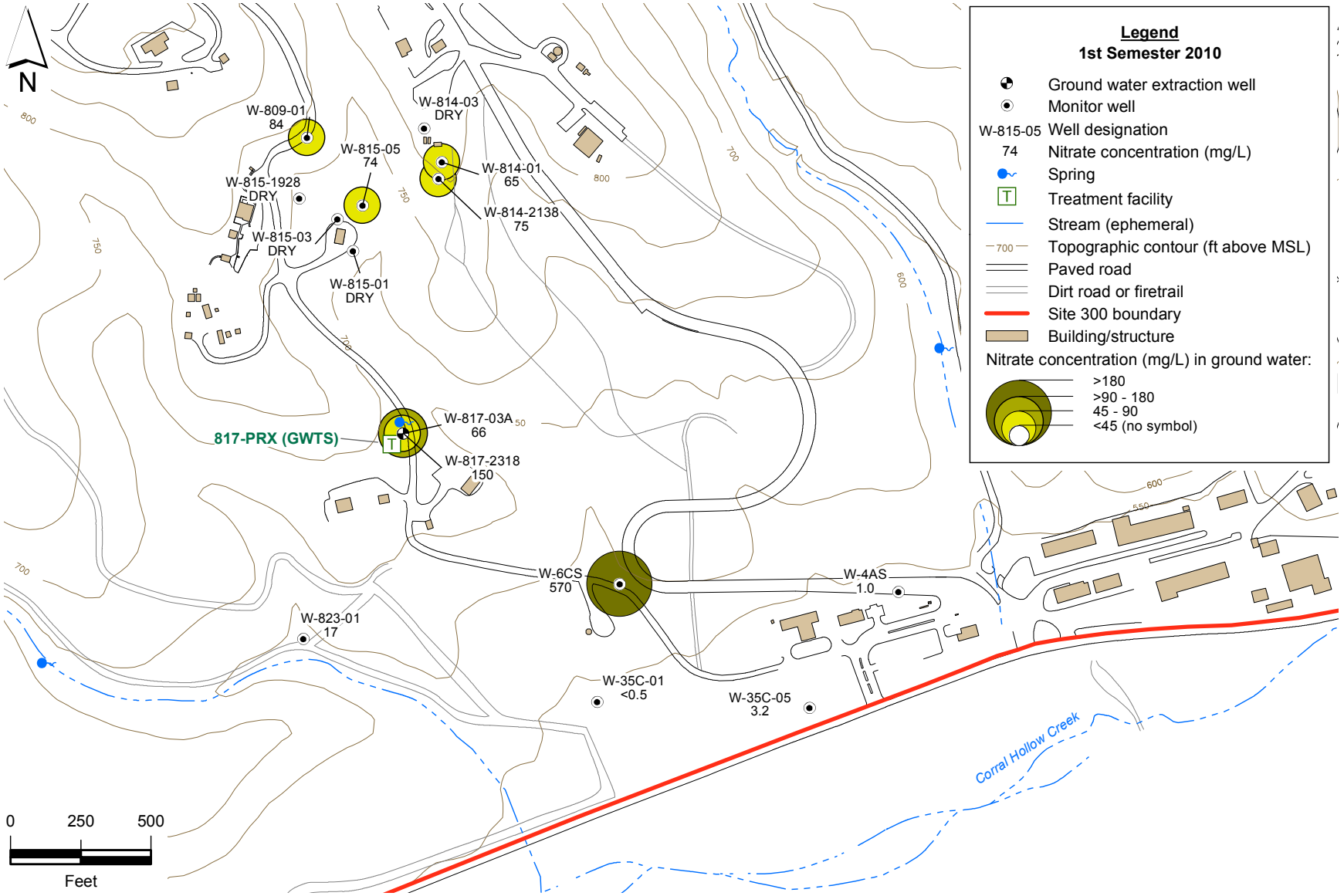


Figure 28. Map showing nitrate concentrations for the Tpsg-Tps hydrostratigraphic unit.

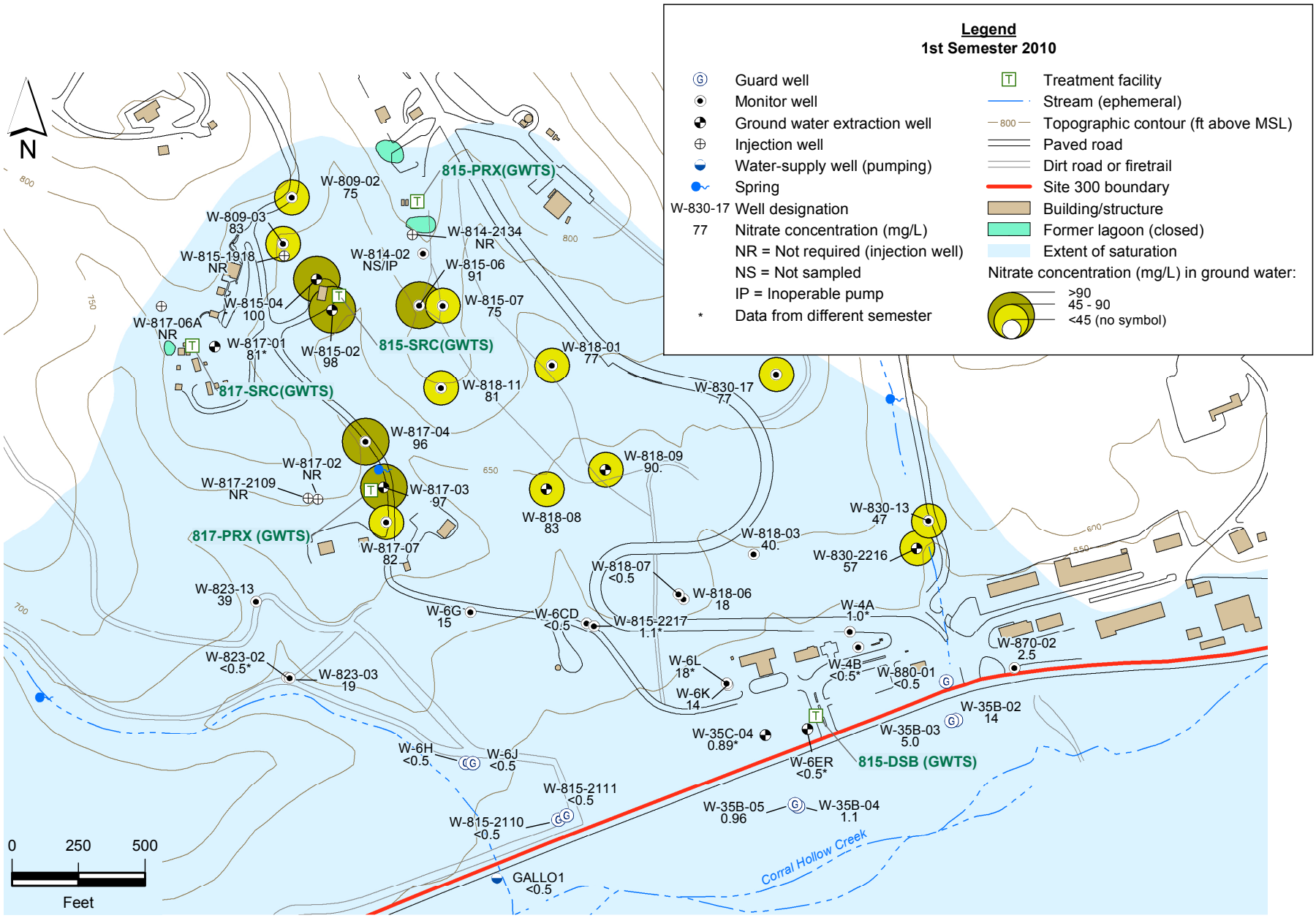


Figure 29. Map showing the distribution of nitrate in the $Tnbs_2$ hydrostratigraphic unit.

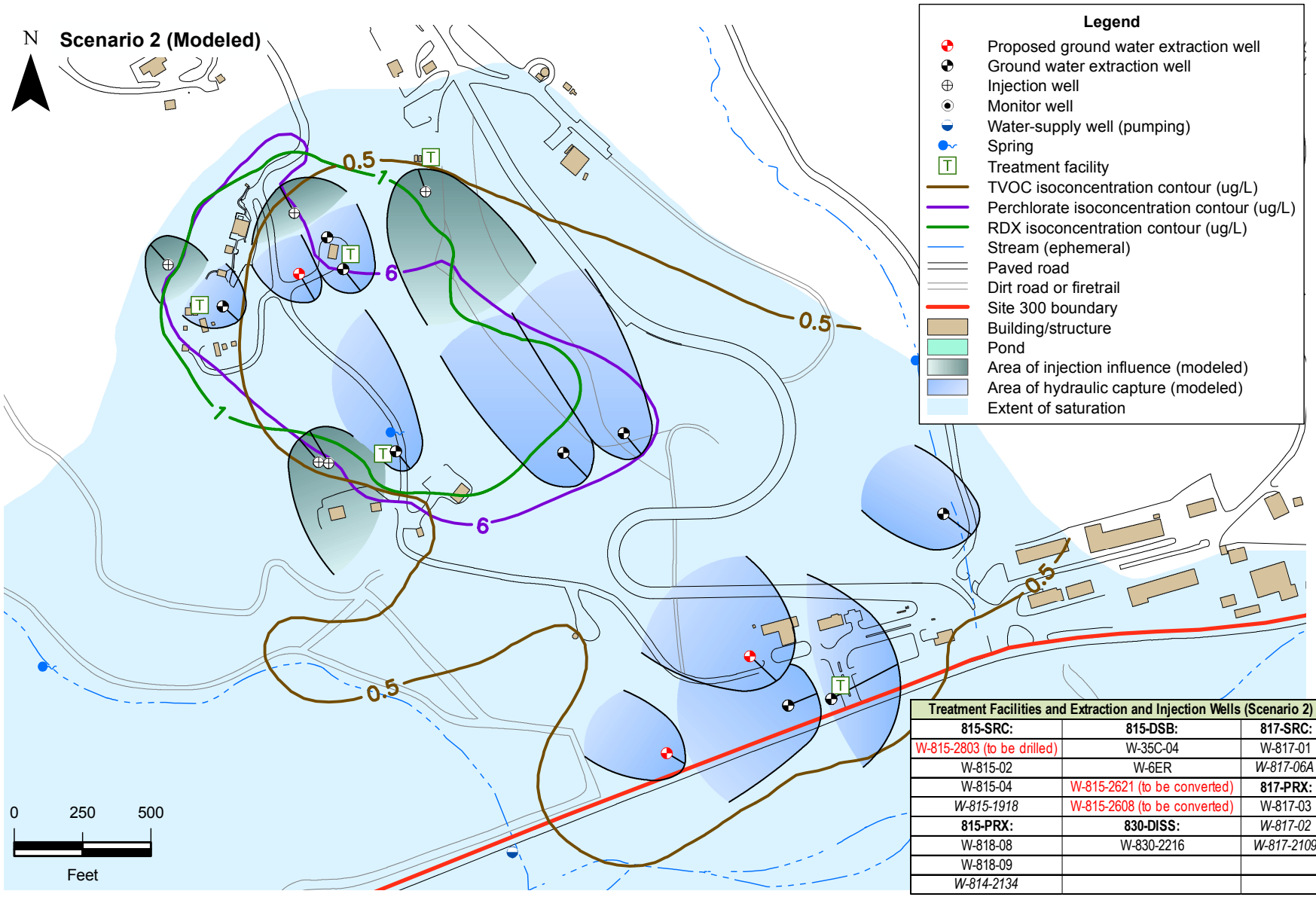


Figure 30. Capture zone analysis results for the Scenario 2 "As Designed" remedial extraction wellfield at the High Explosives Process Area Operable Unit.

Tables

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Table 1. Actual annual costs for the High Explosives Process Area Operable Unit for fiscal years 2007 through 2011.

Fiscal Year	Annual Budget	Actual Annual Cost	Cost Variance
2007	$922,808	$759,748	$163,060[a]
2008	$909,376	$868,033	$41,343[a]
2009	$1,140,609	$927,495	$213,114[b]
2010	$1,073,358	$1,359,225	-$285,867[b]
2011	$1,529,215	$2,208,914	-679,699[c]

Notes:

[a] **The High Explosives Process Area Operable Unit was under budget due to lower than expected operations, maintenance, and optimization costs.**

[b] **Wells budgeted for 2009 were carried-over and installed in 2010.**

[c] **The High Explosives Process Area Operable Unit was over budget during fiscal Year 2011 due to the Building 829-Source engineering assessment and upgrade and Building 815-Distal Site Boundary upgrade and pipeline expansion activities costing more than planned.**

Table 2. Description of institutional/land use controls for the High Explosives Process Area Operable Unit.

Institutional/land use control performance objective and duration	Risk necessitating institutional/land use control	Institutional/land use controls and implementation mechanism
Prevent water-supply use/consumption of contaminated groundwater until ground water cleanup standards are met.	VOCs, RDX, nitrate, and perchlorate concentrations in ground water exceeding drinking water standards.	There are two onsite water-supply wells in the HEPA Operable Unit (Wells 18 and 20). Contamination in HEPA ground water is contained in an aquifer that is 250 ft above, and hydraulically separated from the deeper, clean aquifer in which Well 20 is screened. While Well 18 is no longer used as a water supply well, it is a backup well for emergency fire suppression. Well 18 is cased through the contaminated aquifer. Therefore, onsite workers are not at risk from drinking contaminated water from Wells 18 and 20. Wells 18 and 20 are sampled monthly for contamination. Any proposed well drilling activities would be submitted to the LLNL Work Induction Board, and are reviewed by the LLNL Environmental Restoration Department to ensure that new water-supply wells are not located in areas of ground water contamination. Prohibitions on drilling water-supply wells in areas of ground water contamination will be incorporated into the LLNL Site 300 Integrated Strategic Plan or other appropriate institutional planning documents. Ground water extraction is underway at the site boundary to prevent offsite migration of the VOC plume. Therefore, land use controls are not needed to prevent offsite water-supply use/consumption of contaminated ground water.
Control excavation activities to prevent onsite worker exposure to contaminants in subsurface soil until it can be verified that concentrations do not pose an exposure risk to onsite workers.	Potential exposure to VOCs, HMX, and RDX at depth in subsurface soil at the HEPA OU[a].	All proposed excavation activities must be cleared through the LLNL Work Induction Board and require an excavation permit. The Work Induction Board coordinates with the LLNL Environmental Restoration Department to identify if there is a potential for exposure to contaminants in the proposed construction areas. If a potential for contaminant exposure is identified, LLNL Hazards Control ensures that hazards are adequately evaluated and necessary controls identified and implemented prior to the start of work. The Work Induction Board including the LLNL Environmental Analyst will also work with the Program proposing the construction project to determine if the work plans can be modified to move construction activities outside of areas of contamination.
Maintain land use restriction in the vicinity of Building 815 until annual risk re-evaluation indicates that the risk is less than 10^{-6}.	Pre-remediation risk of 5×10^{-6} for onsite workers from inhalation of VOCs volatilizing from the subsurface soil into outdoor air in the vicinity of Building 815.	This risk has been successfully mitigated since 2004 through ground water extraction and treatment, therefore this institutional/land use control is no longer needed.

Table 2. Description of institutional/land use controls for the High Explosives Process Area Operable Unit. (Continued)

Institutional/land use control performance objective and duration	Risk necessitating institutional/land use control	Institutional/land use controls and implementation mechanism
Maintain land use restriction in the vicinity of Spring 5 until annual risk re-evaluation indicates that the risk is less than 10^{-6}.	1 x 10^{-5} risk for onsite workers continuously inhaling VOC vapors volatilizing from Spring 5 into outdoor air over a 25-year period.	The spring has been dry since 2003. There are currently no active facilities located in the vicinity of the Spring 5 and there is no surface water present in the spring. Current activities in the vicinity of the Spring 5 are restricted to semi-annual spring sampling. The time spent sampling is well below the exposure scenario for which the unacceptable exposure risk was calculated, which assumed a worker would spend 8 hours a day, five days a week for 25 years working at Spring 5. DOE will conduct annual risk re-evaluations when water is present in Spring 5 to determine when the inhalation risk has been mitigated. The risk re-evaluation results will be reported in the Annual Site-Wide Compliance Monitoring Reports. Any significant changes in activities conducted in the Spring 5 area must be cleared through LLNL Work Induction Board. The Work Induction Board coordinates with the LLNL Environmental Restoration Department to identify if there is a potential for exposure to contaminants as a result of the proposed area usage. If a potential for contaminant exposure is identified as a result of these changes in activities or area use, LLNL Hazards Control is notified and determines any necessary personal protective equipment to prevent exposure.
Prohibit transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use.	Potential exposure to contaminated waste and/or environmental media.	The Site 300 Federal Facility Agreement contains provisions that assure that DOE will not transfer lands with unmitigated contamination that could cause potential harm. In the event that the Site 300 property is transferred in the future, DOE will execute a land use covenant at the time of transfer in compliance with Title 22 California Code of Regulations, Division 4.5, Chapter 39, Section 67391.1. Development will be restricted to industrial land usage. These restrictions will remain in place until and unless a risk assessment is performed in accordance with then current U.S. EPA risk assessment guidance and is agreed by the DOE, the U.S. EPA, DTSC, and the RWQCB as adequately showing no unacceptable risk for residential or unrestricted land use. These restrictions will be incorporated into the LLNL Site 300 Integrated Strategic Plan or other appropriate institutional planning document.

Notes appear on the following page.

Table 2. Description of institutional/land use controls for the High Explosives Process Area Operable Unit. (Continued)

Notes:

DOE = United States Department of Energy.

DTSC = California Department of Toxic Substances Control.

U.S. EPA = United States Environmental Protection Agency.

HEPA = High Explosives Process Area.

HMX = High melting explosive.

LLNL = Lawrence Livermore National Laboratory.

RDX = Research department explosive.

RWQCB = California Regional Water Quality Control Board.

VOCs = Volatile organic compounds.

[a] **Risk for onsite worker exposure to VOCs, RDX, and HMX at depth in subsurface soil during excavation activities was not calculated as this was not considered a long-term exposure scenario. As a result, land use controls based on the potential exposure to VOCs, RDX, and HMX in subsurface soil during excavation conservatively assume that the these COCs in subsurface soil may pose a risk to human health.**

Table 3. Historical and current maximum concentrations of trichloroethene (TCE), Research Department Explosive (RDX), perchlorate, and nitrate by hydrostratigraphic unit (HSU) in the High Explosives Process Area Operable Unit compared to ground water cleanup standards.

		Historical Maximum			First Semester 2011 Maximum			
HSU	Constituent	Concentration	Sample Location	Sample Date	Concentration	Sample Location	Sample Date	Cleanup Standard
Tpsg-Tps								
	TCE	450 µg/L	W-815-01	May-92	53 µg/L	W-817-2318	Apr-11	5 µg/L
	RDX	350 µg/L	W-815-01	Mar-88	<1 µg/L	All wells	NA	1 µg/L
	Perchlorate	17 µg/L	W-817-2318	Mar-08	14 µg/L	W-817-2318	Apr-11	6 µg/L
	Nitrate[a]	160 mg/L	W-817-2318	Apr-11	160 mg/L	W-817-2318	Apr-11	45 mg/L
$Tnbs_2$								
	TCE	110 µg/L	W-818-08	May-92	40 µg/L	W-818-08	Apr-11	5 µg/L
	RDX	204 µg/L	W-817-01	Jul-92	106 µg/L	W-809-03	Mar-11	1 µg/L
	Perchlorate	50 µg/L	W-817-01	Feb-98	29 µg/L	W-817-01	May-11	6 µg/L
	Nitrate	140 mg/L	W-809-02	Jan-11	100 mg/L	W-815-02 and W-815-04	Feb-11	45 mg/L
$Tnsc_{1b}$								
	TCE	1000 µg/L	W-829-06	Aug-93	8.1 µg/L	W-829-06	Mar-11	5 µg/L
	RDX	NA	NA	NA	NA	NA	NA	1 µg/L
	Perchlorate	29 µg/L	W-829-06	Dec-00	7.2 µg/L	W-829-06	Mar-11	6 µg/L
	Nitrate	240 mg/L	W-829-06	Dec-00	56 mg/L	W-829-06	Mar-11	45 mg/L

Notes:

mg/L = **Milligrams per liter.**

NA = **Not applicable.**

µg/L = **Micrograms per liter.**

[a] **Excluding near sheep ranch well W-6CS.**

Table 4. Contaminants of Concern, Startup Dates, Extraction Wells and Hydrostratigraphic Unit (HSU) Completion for the HEPA Ground Water Extraction and Treatment Systems.

Treatment Facility	Contaminants of Concern (COCs)	Year of Facility Startup	Existing Extraction Wells	HSU	Proposed New Extraction Wells (EW) and Monitor Wells (MW)
815-SRC	VOCs	September-00	W-815-02, W-815-04	$Tnbs_2$	$Tnbs_2$ EW: W-815-2803
	HE compounds				
	Perchlorate				
	Nitrate (as NO_3)[a]				
815-PRX	VOCs	October-02	W-818-08, W-818-09	$Tnbs_2$	None
	Perchlorate				
	Nitrate (as NO_3)[a]				
815-DSB	VOCs	September-99	W-35C-04, W-6ER	$Tnbs_2$	$Tnbs_2$ EWs: W-815-2803, -2621 Tpsg-Tps MW: W-815-2XM1
817-SRC	HE compounds	September-03	W-817-01	$Tnbs_2$	$Tnbs_2$ MW: W-817-2XM1
	Perchlorate				
	Nitrate (as NO_3)[a]				
817-PRX	VOCs	September-05	W-817-03, W-817-04; W-817-2318	$Tnbs_2$, Tpsg-Tps	None
	HE compounds				
	Perchlorate				
	Nitrate (as NO_3)[a]				
829-SRC	VOCs	August-05	W-829-06	$Tnsc_{1b}$	None
	Perchlorate				
	Nitrate (as NO_3)				

Notes appear on the following page.

Table 4. Contaminants of Concern, Startup Dates, Extraction Wells and Hydrostratigraphic Unit (HSU) Completion for the HEPA Ground Water Extraction and Treatment Systems. (Continued)

Notes:

HE = High explosives.

HSU = Hydrostratigraphic unit.

VOCs = Volatile organic compounds.

[a] **Nitrate-bearing water is reinjected to the subsurface to naturally attenuate through microbial denitrification, following treatment to remove other contaminants of concern.**

Appendix A

Ground Water Flow and Contaminant Transport Modeling in the $Tnbs_2$ Hydrostratigraphic Unit

Appendix A

Ground Water Flow and Contaminant Transport Modeling in the $Tnbs_2$ Hydrostratigraphic Unit

A-1. Objective

The primary objective of the ground water flow and contaminant transport modeling was to estimate capture zones in the $Tnbs_2$ Hydrostratigraphic Unit (HSU) based on two scenarios: 1) the existing extraction wellfield and 2) the "As Designed" expanded extraction wellfield. The model was also used to develop preliminary estimates of the time required to achieve cleanup standards within the $Tnbs_2$ HSU using the Scenario 2, "As Designed" extraction wellfield. In addition, the model serves as a framework for organizing field and laboratory data and provides a decision-making tool that can be used to refine DOE/LLNL's understanding of groundwater flow and contaminant transport within the High Explosives Process Area (HEPA) Operable Unit (OU). The model was used to simulate the transport of trichloroethene (TCE), a primary contaminant of concern (COC) in the HEPA OU, and Research Department Explosive (RDX) and perchlorate, two secondary COCs.

A-2. Conceptual Model

The $Tnbs_2$ HSU model simulated single-phase (saturated-zone) ground water flow within a single HSU. The $Tnbs_2$ HSU was modeled as a confined aquifer, although actual field conditions vary from unconfined to confined. This assumption of confined aquifer conditions is common and provides a reasonable approximation of field conditions without adding unnecessary complexity in the initial stages of model development. The conceptual model of flow and transport within the $Tnbs_2$ HSU is described in Section 3 (Background) of this report.

The following assumptions apply:

- The model was built by discretizing a single layer into three dimensions; however, due to vertically averaged properties, it is representative of a two-dimensional domain.
- The model solves for steady-state ground water flow and transient transport.
- The $Tnbs_2$ HSU is homogeneous and isotropic within distinct zones.
- TCE, RDX and perchlorate were the only chemical species modeled.
- Retardation effects were considered.
- Flow and transport occur only through porous media. Fracture flow is ignored.
- Biological effects are assumed negligible.
- Model is isothermal.

A-3. Model Description

A-3.1. Numerical Code

All modeling was conducted using FEFLOW, a Finite Element subsurface FLOW and transport simulation system developed at the Institute for Water Resources Planning and Systems Research, Ltd. (Diersch, 1998). Version 4.8, which was used for the simulations, features an interactive graphical interface and PEST, an add-in module for automated parameter estimation. Details about the equations governing ground water flow and contaminant transport are included in FEFLOW's reference manual (Diersch, 1998).

A-3.2. Model Domain and Grid

Figure A-1 shows the domain developed for the $Tnbs_2$ HSU FEFLOW model. The northern, eastern, and western boundaries of the model domains were chosen to approximately outline the lateral extent of saturation within the $Tnbs_2$ HSU. The southern boundary extends past the site boundary and Corral Hollow Road to include data from offsite wells. The initial model domain for the $Tnbs_2$ HSU had 38,144 elements and 29,151 nodes, and covered approximately 229 acres. The irregular, finite element mesh was created using FEFLOW's automated mesh generation program. The mesh was refined near the source areas to minimize problems with numerical dispersion during the transport calibration. Figure A-2 shows a three-dimensional visualization of the grid used for the model. The $Tnbs_2$ HSU was modeled as a separate 3-dimensional layer. Mass balances were checked after the flow and transport calibration to confirm that the mesh was adequately refined.

A-3.3. Boundary Conditions, Aquifer Type, Top and Bottom Layers

Boundary conditions were selected based on an analysis of expected recharge to and discharge from, the $Tnbs_2$ HSU. Recharge to the model was primarily along the northern boundary and through areal recharge. The northern boundary represents inflow from the catchment area where the $Tnbs_2$ stratigraphic units are exposed at the surface and from where narrow canyons intersect with the model boundaries. Areal recharge was applied in the northernmost, unconfined portions of the aquifer. Discharge was expected to occur along the southeastern border of the model where the $Tnbs_2$ HSU sub-crops beneath the Quaternary alluvium HSU and an upward gradient is present. Boundary conditions for the model are shown on Figure A-1. Boundaries with a net influx of groundwater are shown in red and discharge boundaries are shown in blue. Offsite water supply well Gallo1 was set a constant extraction flow rate of 1 gallon per minute (gpm) in some scenarios. This well is typically operated intermittently at higher flow rates; however, a conservative average extraction flow rate was selected to be consistent with long-term observed ground water elevations.

Recharge and discharge model boundaries were initially set as constant head based on ground water elevation data, and revised as appropriate during the flow calibration (see Section A-3.5). The top boundary conditions of the model represent areal recharge in the unconfined portions of the aquifer. Bottom boundaries of the model were no flow, and the surfaces used to create these layers were imported from a 3-dimensional (3-D) geologic model specifically developed for the southeast corner of Site 300. Boundary conditions have a considerable impact on ground water elevation and plume migration patterns.

A-3.4. Input Parameters

A-3.4.1. Flow Model Input Parameters

Hydraulic conductivity is important in determining boundary fluxes, water levels, and plume migration patterns. For the $Tnbs_2$ HSU, hydraulic conductivity for the calibrated model was approximately 0.8 feet per day (ft/day) throughout most of the domain and 0.4 ft/day in a 250-foot-wide fault zone located perpendicular to Route 3 and north of Building 823 (Figure A-1). Hydraulic conductivity within the aquifer was calibrated as described in Section A-3.5.1. A uniform hydraulic conductivity (K) (uniform within discrete zones) was used to better match the observed ground water elevation data and to match the lower yields observed near the fault zone. Hydraulic conductivities used to model the $Tnbs_2$ HSU in the Site Wide Remediation Evaluation Summary Report for LLNL Site 300 (Ferry, et. al. 1996) were 0.68 ft/day in the primary domain and 0.31 ft/day in the fault zone.

A-3.4.2. Transport Model Input Parameters

A porosity value of 0.32 was chosen using average core porosity measured during laboratory testing (Madrid and Jakub, 1998). Initial concentrations of TCE, RDX and perchlorate used for production runs were based on Annual 2010 Compliance Monitoring Report (Dibley et al., 2011) data. Concentrations were entered into FEFLOW at discrete points, and the program's linear interpolation scheme was used to assign values between data points. Minor adjustments were also made to ensure that the maximum concentrations in the initial concentration array matched the observed data. Values of less than 1 microgram per liter (µg/L) of a contaminant were set to a very low value to minimize problems with numerical dispersion during initial time steps. Plume migration patterns are affected by the values of longitudinal and transverse dispersivities. A longitudinal dispersivity of 10 feet (ft) and a transverse dispersivity of 1 ft, or 10% of the longitudinal dispersivity, were used for the cleanup time simulations. Both the longitudinal and transverse dispersivities were calibrated as part of the transport calibration process.

A-3.5. Calibration

A-3.5.1. Flow Calibration

The $Tnbs_2$ HSU FEFLOW model was calibrated using FEFLOW's automated parameter estimation tool (PEST), which minimized the sum of the squared differences between measured and modeled head data at multiple observation wells located within the model domain. The initial hydraulic conductivities input entered into PEST were 1 ft/day for the primary model domain and 0.1 ft/day for the fault zone. This range matched the values used to model the $Tnbs_2$ HSU in the *Final Site-Wide Remediation Summary Report* (SWRSR) (Ferry et al., 2006). Calibrated values as shown on Figure A-1 ranged from 0.4 to 0.8 ft/day. After initial calibration with PEST, minor (< 2 ft) adjustments in the initial specified head data used as boundary conditions were made to improve calibration results. The resulting ground water elevation maps were also subject to visual inspection to confirm the direction of the flow gradient. Recharge to the model of 2,498 cubic feet per day (cfd) through the northern boundary and via areal recharge was compared with independent estimates of recharge from 925 to 3,655 cfd that were determined considering the size of the catchment area (Pelmulder and Maxwell, 1997).

Figure A-3 shows a comparison between 1999 measured and modeled ground water elevation data. Ground water elevation data collected in 1999 were used for the initial

calibration. A steady-state pumping rate of 1 gallon per minute (gpm) at offsite water-supply well Gallo1 was assumed. The flow model was calibrated by comparing measured and modeled ground water elevation during a number of stressed and unstressed periods including 1999, 2005, 2006 and 2007. For each time period, the calibration was evaluated by visually comparing the measured and modeled data and by using an objective function, R^2. R^2 is defined as $R^2=1-\sum [(\text{measured}_i-\text{predicted}_i)2/(\text{mean measured}_i)2]$, where measured$_i$ are the measured ground water head data, predicted$_i$ are the modeled ground water head data, and mean is the mean of measured ground water head data.

A-3.5.2. Transport Calibration

The $Tnbs_2$ FEFLOW model relies primarily on the flow calibration to ensure robustness; however, some transport parameters (longitudinal and transverse dispersivity) were also calibrated. The calibrated longitudinal dispersivity that best matched the observed data was 10 ft and the calibrated transverse dispersivity that best matched the observed data was 1 ft, or 10% of the longitudinal dispersivity.

The $Tnbs_2$ transport calibration was achieved by recreating the present-day TCE plume using a mass flux term applied at the source area. For this calibration, a 0.0025 milligram per liter (mg/L) point source was applied at the primary TCE source area, Building 815. The point source was a "step function" that was applied at a constant rate for 25 years, approximating the period between 1955 to 1980. The contaminant plume was then observed after another 30 years of transient transport and compared with present-day (second quarter 2010) TCE data. To improve the transport calibration, longitudinal and transverse dispersivities were then adjusted and the transport calibration rerun if necessary.

Results of the $Tnbs_2$ HSU transport calibration found that a source term of 0.0025 mg/L applied for 25 years was able to match the general plume shape and concentration distributions in the upper and middles portions of the $Tnbs_2$ HSU. The capability of the model to match observed data using a 'step-function' point source suggests that the Building 815 Source Area is no longer contributing significant mass to the TCE plume within the $Tnbs_2$ HSU. It also verifies the validity of the $Tnbs_2$ HSU conceptual model. Nevertheless, using a single point source, the model was not able to match TCE concentrations near the site boundary. This suggests that another source, probably located in the Building 832 Canyon OU, may have contributed to the TCE plume in this area.

Intermittent pumping at onsite and offsite water supply wells such as Well 6 (now abandoned) and GALLO1 have also impacted the spatial distribution of TCE in the $Tnbs_2$ HSU. As a result, a closer match between the measured and modeled concentration data is not likely using a steady-state flow model. Offsite water supply well GALLO1 was pumped at a constant rate of 1 gpm during the transport calibration. Well 6 pumping was not included.

A-4. Model Results

To evaluate capture zones, two flow scenarios were considered. Scenario 1 was simulated using the extraction wells, injection wells and flow rates that were typical of wellfield operations during the past five years. The extraction and injection wells and capture zones associated with this scenario are shown on Figure A-4. Scenario 2 (also shown on Figure A-4) was simulated using the "As Designed" extraction wellfield. This wellfield included proposed 815-SRC

extraction well W-815-2803, and 815-DSB extraction wells W-815-2608 and W-815-2621 (both wells are currently monitor wells). Proposed extraction wells are shown in red. Scenario 2 also included increased pumping from the 815-PRX and 817-PRX extraction wells. To represent intermittent pumping at offsite water-supply well GALLO1, the well was pumped at a flow rate of 1 gpm during the steady-state simulations.

As shown on Figure A-4, the Scenario 2 "As Designed" extraction wellfield is expected to expand the areas of hydraulic capture, yet low yields and steep topography continue to limit the locations where new extraction and injection wells may be installed. Based on previous modeling studies, the HEPA OU has a long-term sustainable yield of 15-20 gpm (Ferry et al., 2006). To minimize pulling contaminants toward the Site 300 boundary, pumping at 815-DSB is balanced with upgradient pumping at the Building 815 and 817 source areas.

Distributions of TCE, RDX, and perchlorate within the model domain after 25 years of pumping using the Scenario 2 "As Designed" extraction wellfield are shown in Figure A-5. RDX has a high retardation factor and tends to sorb onto the porous media, making it not only less mobile than the TCE or perchlorate, but also more difficult to remediate. These simulations (Figure A-5) indicate that TCE, RDX and perchlorate plume concentrations greater than drinking water standards will persist after 25 years of cleanup.

A-5. Cleanup Times Estimates

The FEFLOW model was used to make preliminary estimates of the time required to clean up the TCE, RDX, and perchlorate plumes in the $Tnbs_2$ HSU to a cleanup standard of 5 µg/L, 1 µg/L and 6 µg/L respectively. The predictions were simulated using the Scenario 2 "As Designed" extraction wellfield with constant flow rates specified at each existing and proposed extraction well. The wells used in the Scenario 1 and Scenario 2 simulations are shown on Figure A-4. To represent intermittent pumping, offsite water-supply well Gallo1 was pumped at a constant rate of 1 gpm.

For all three COCs, it was assumed that the HEPA source areas did not continue to contribute mass beyond what was initially present. It was also assumed that extraction wellfields remained unchanged over time; however, in reality, optimization of the extraction wellfields could significantly reduce future cleanup time estimates.

As shown on Figure A-6, the time required to cleanup the $Tnbs_2$ HSU to the appropriate cleanup standard under non-optimized conditions was approximately 100 years for TCE, 445 years for RDX and 45 years for perchlorate. The dashed portions of the curves shown on Figure A-6 indicates the increasing uncertainty that exists in all model predictions as the estimated time period moves farther from the initial conditions. The retardation factors used for the simulations were 3.1 for TCE, 4.2 for RDX, and 1.0 for perchlorate. To better match the SWRSR (Ferry et al, 2006) modeling studies, the RDX retardation factor was increased to 6.6, resulting in cleanup times estimates of 700 years for cleanup of RDX to 1 µg/L. Based on the modeling studies done in the SWRSR (Ferry et al., 2006), estimates of cleanup times to 5 µg/L for TCE ranged from 110-120 years and estimates of cleanup times for RDX to 1 µg/L ranged from 800-1000 years. Due to the uncertainty associated with the modeling process, cleanup times for the $Tnbs_2$ HSU are expected to fall within a range of plus or minus twenty-five years.

A-6. Conclusions

This appendix provides an overview of the FEFLOW model used for the HEPA OU.

The following conclusions were derived from the modeling:

- Figure A-4 shows the capture zones estimated using the Scenario 1 "Five-year Average" and Scenario 2 "As Designed" extraction wellfields. The wells associated with each scenario are listed on this figure. As depicted, potential new extraction wells W-815-2621 and W-815-2608 (shown in red) are expected to increase hydraulic capture near the site boundary. Proposed extraction well W-815-2803 (also shown in red) is expected to increase hydraulic capture near the 815-SRC treatment facility. Figure A-4 also shows the estimated impact of increased extraction flow rates from 817-PRX extraction well W-817-03 and 815-PRX extraction wells W-818-08 and W-818-09.
- Figure A-5 depicts the spatial distributions of TCE, RDX, and Perchlorate after 25 years of pumping using the Scenario 2 "As Designed" extraction wellfield. Simulations of cleanup under non-optimized conditions in the $Tnbs_2$ HSU using this pumping scenario indicate that TCE, RDX, and perchlorate plume concentrations greater than drinking water standards are expected to persist after 25 years of pumping.
- As shown on Figure A-6, the time required to achieve cleanup of TCE to the 5 µg/L cleanup standard was estimated to be 100 years as compared to the 110-120 years predicted by the SWRSR modeling studies (Ferry et al., 2006). Perchlorate contamination is contained within the footprint of the TCE plume and is expected to be cleaned up in a shorter duration of time. Optimization of the extraction wellfields may reduce future cleanup time estimates.
- Also shown on Figure A-6, cleanup time estimates for RDX under non-optimized conditions extend into the hundreds of years due to the highly sorptive nature of this contaminant. Sorption tends to impede cleanup, leading to longer cleanup times. In implementation; however, DOE/LLNL will continuously monitor the remediation of the RDX plume to better target contaminants and to minimize cleanup times.
- Results of the $Tnbs_2$ transport calibration found that a source term of 0.0025 mg/L applied near the Building 815 source area for 25 years was able to match the general plume shape and concentration distributions. A closer match is not likely using a steady-state approximation of intermittent pumping at water supply Well 6 (now abandoned) and offsite water supply well Gallo1. The capability of the model to match the spatial distribution of observed TCE concentration data using a 'step-function' point source suggests that the Building 815 Source Area is no longer contributing significant mass to the TCE plume within the $Tnbs_2$ HSU. Other sources, including sources located in the Building 832 Canyon OU, may also be contributing to the TCE plume within the $Tnbs_2$ HSU.
- All hydraulic capture zones shown in this appendix are conservative estimates based on model results. Observed capture zones may be significantly larger due to the presence of interconnected fracture networks.

A-7. References

Diersch, H. G. (1998), Reference Manual, "FEFLOW- Interactive, Graphics-based Finite-Element Simulation System for Modeling Ground water Flow, Contaminant Mass and Head Transport Processes," WASY Institute for Water Resources Planning and Systems Research Ltd., Berlin, Germany.

Ferry, L., M. Dresen, Z. Demir, V. Dibley, V. Madrid, M. Taffet, S. Gregory, J. Valett, M. Denton (2006), *Final Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-220391).

Madrid, V. M. and B. J. Jakub (1998), *Engineering Evaluation/Cost Analysis for the Building 815 Operable Unit Removal Action Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-126639).

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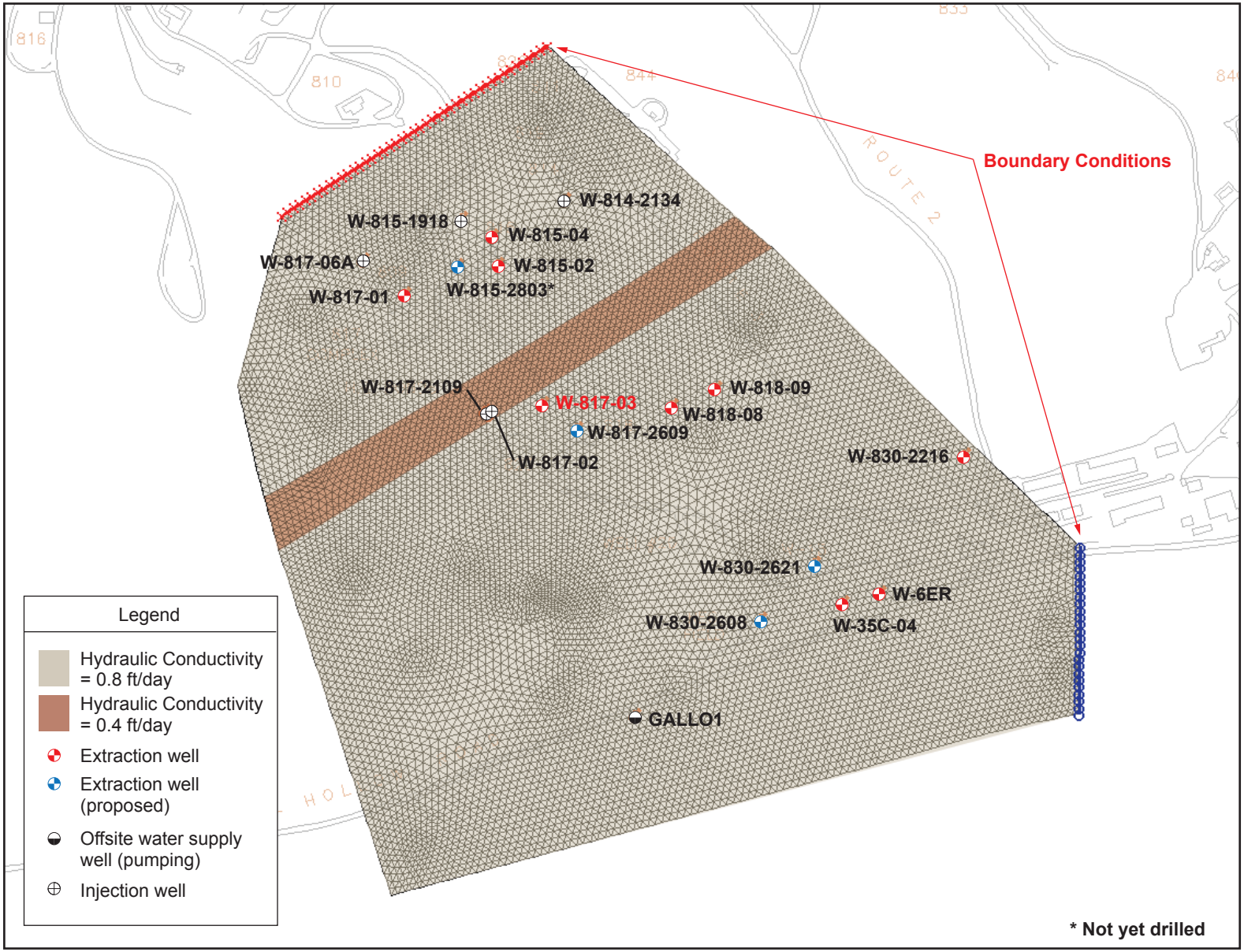
U.S. DOE (2008), *Final Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-236665).

Appendix A

Figures

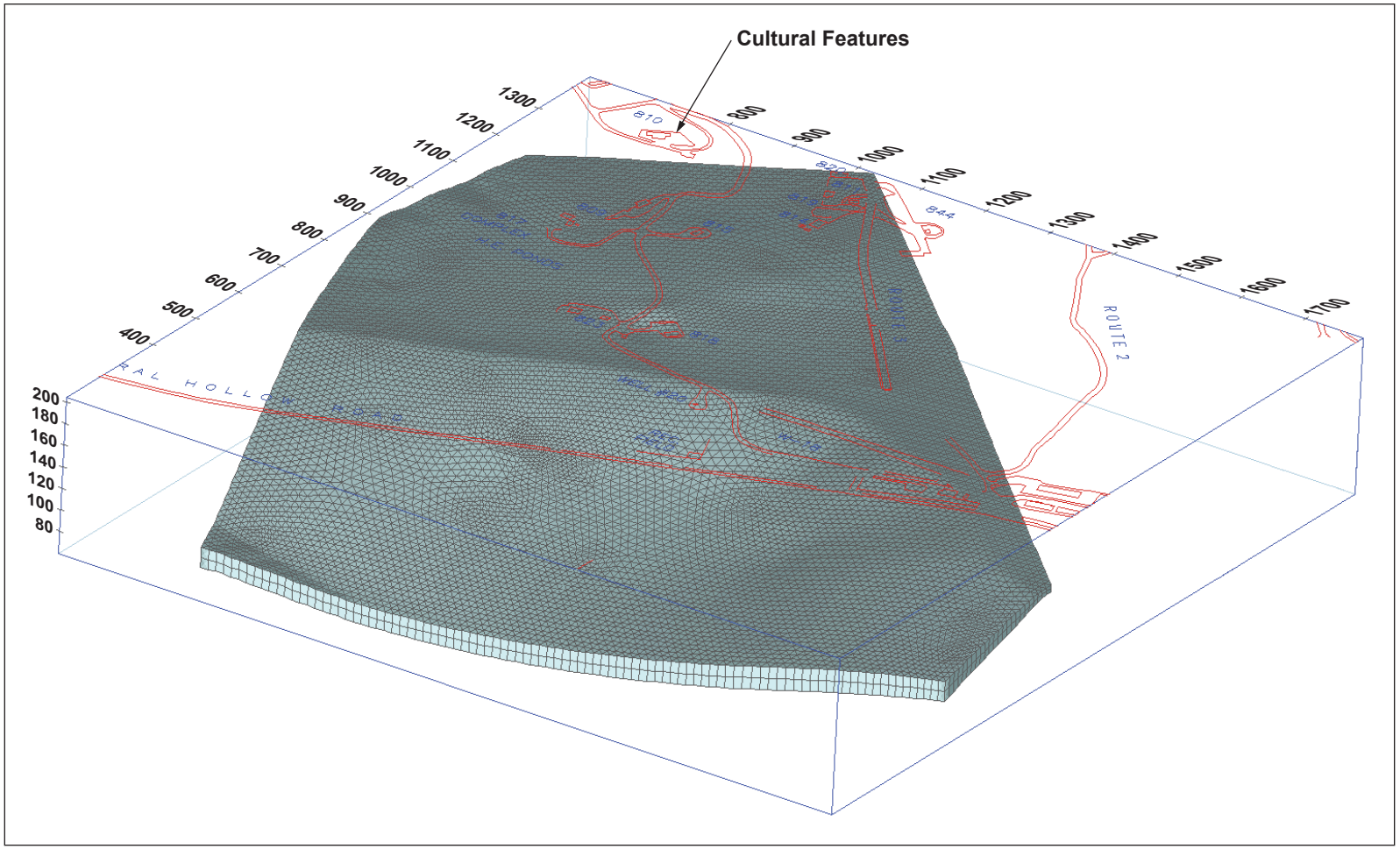
Appendix A

List of Figures



ERD-S3R-11-0180

Figure A-1. Map showing the $Tnbs_2$ FEFLOW model domain, grid, boundary conditions, hydraulic conductivity field, cultural features and location of existing and proposed extraction wells included in the Scenario 2 "As Designed" simulation.



ERD-S3R-11-0181

Figure A-2. A three-dimensional visualization of the finite-element grid used for the $Tnbs_2$ FEFLOW model.

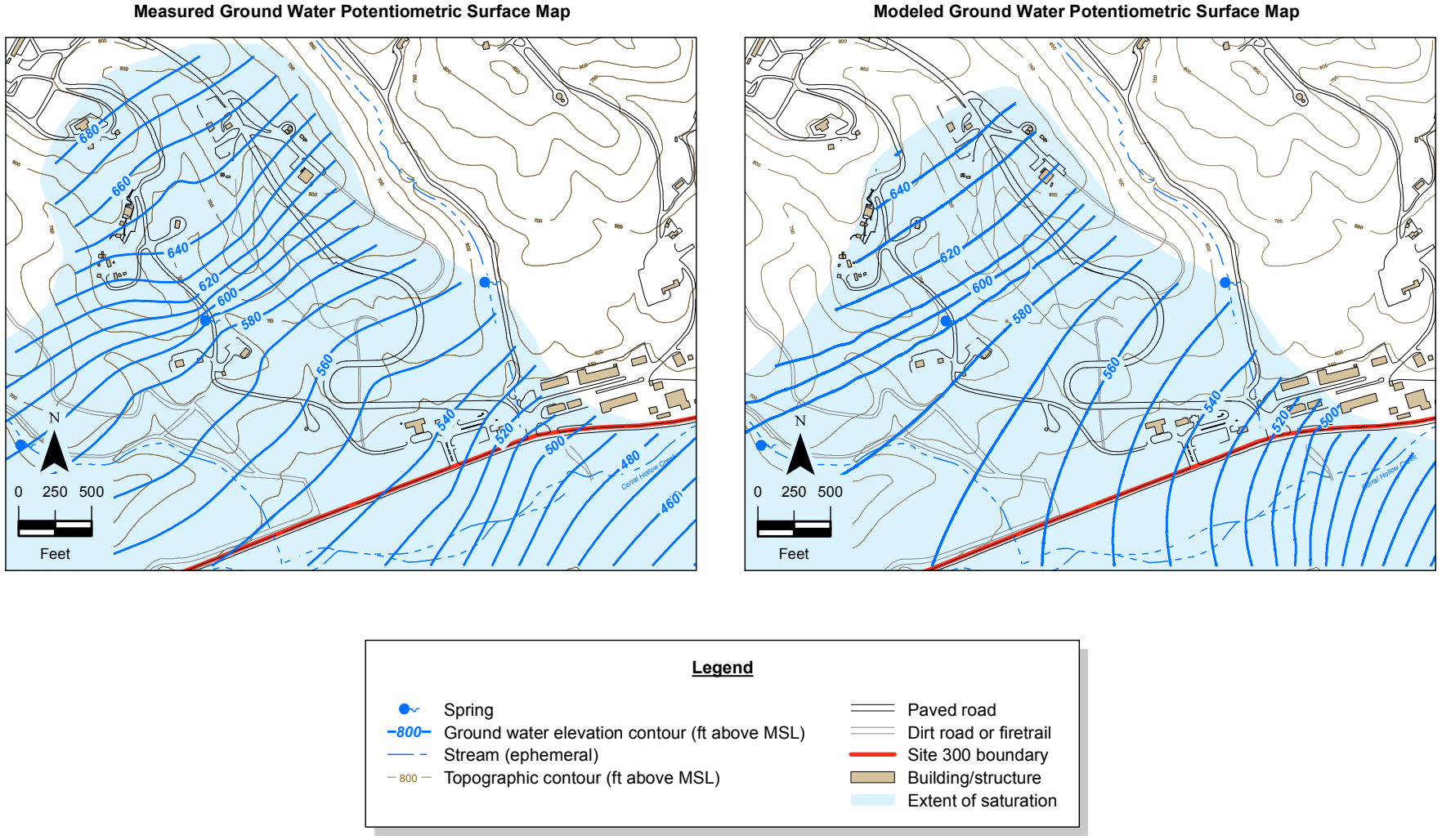
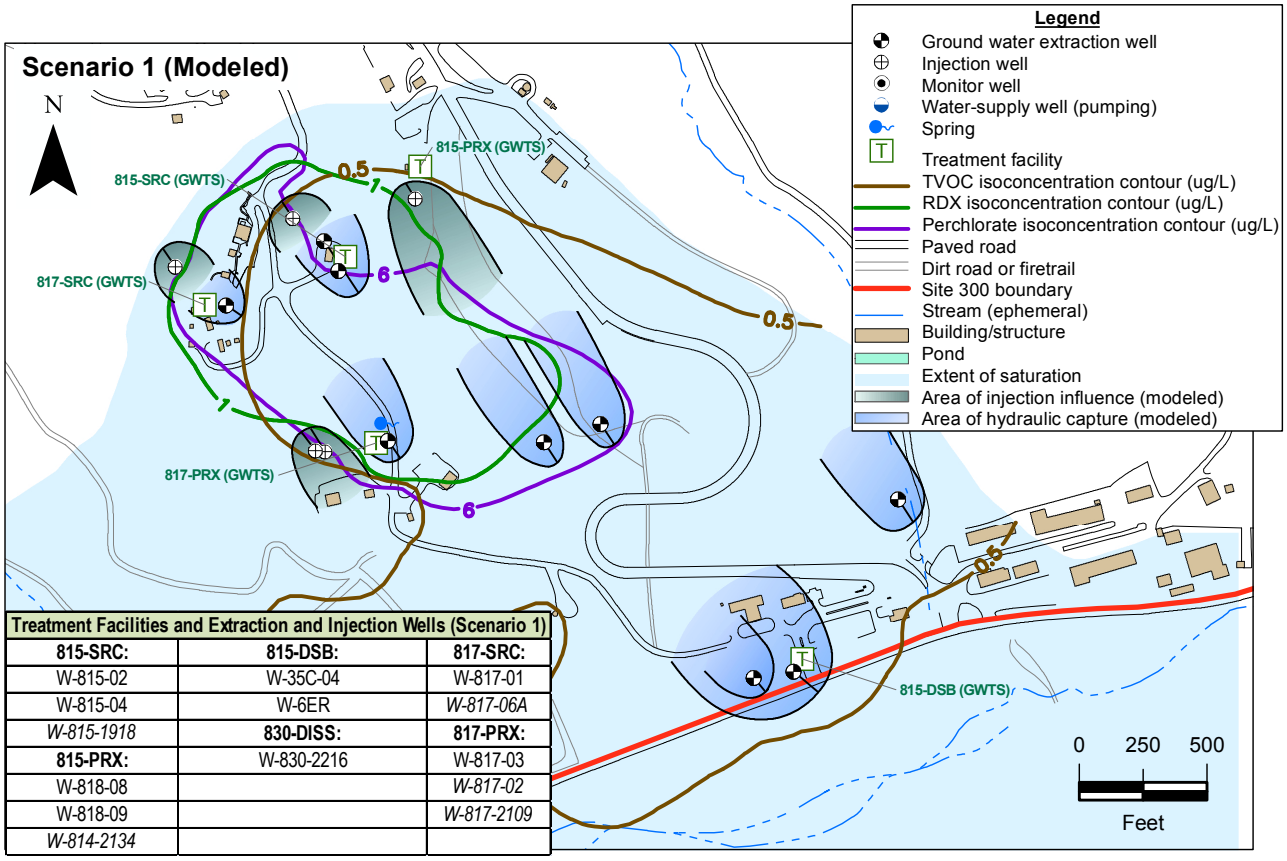
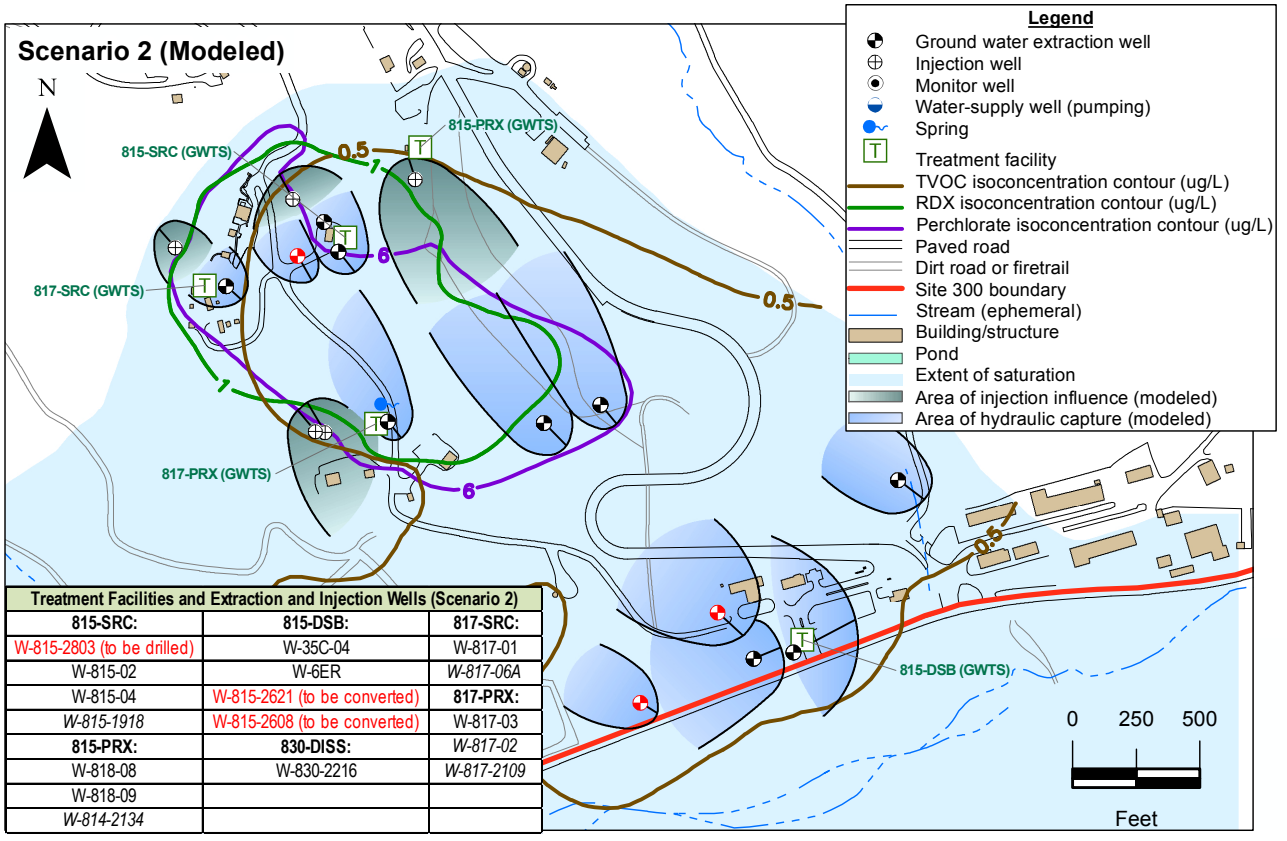


Figure A-3. Measured and modeled ground water potentiometric surface maps used for and resulting from the $Tnbs_2$ FEFLOW model calibration.

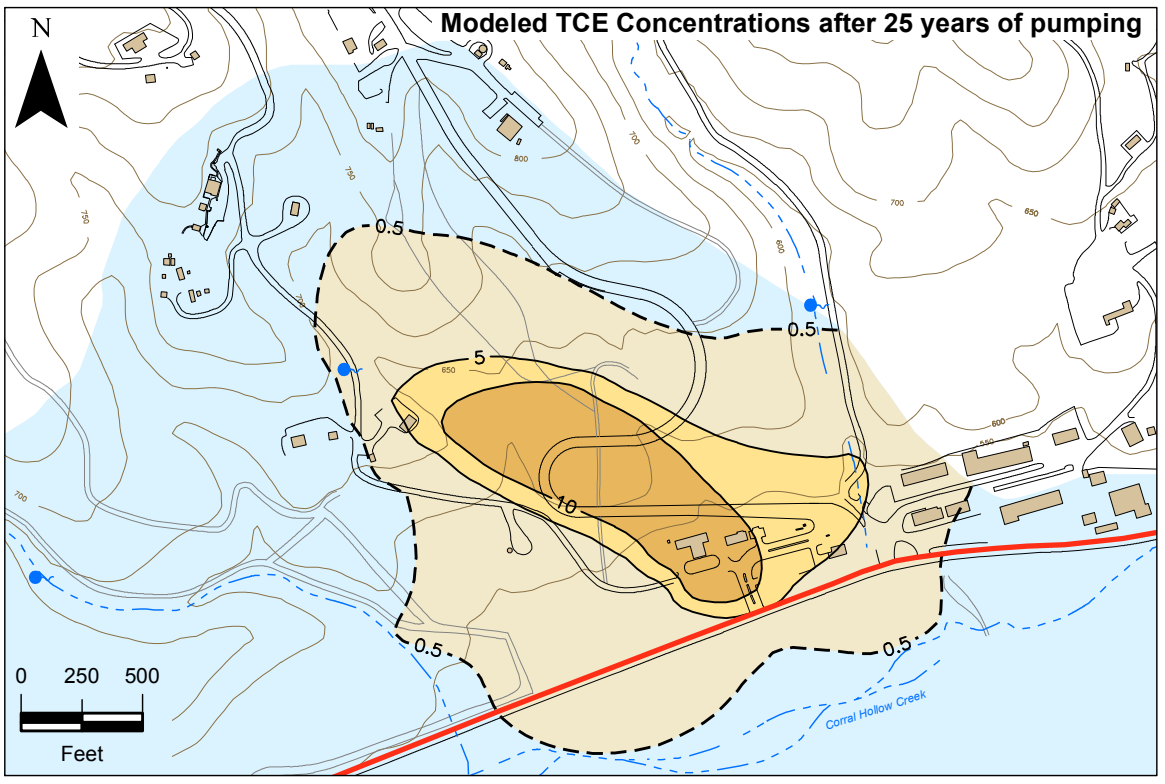


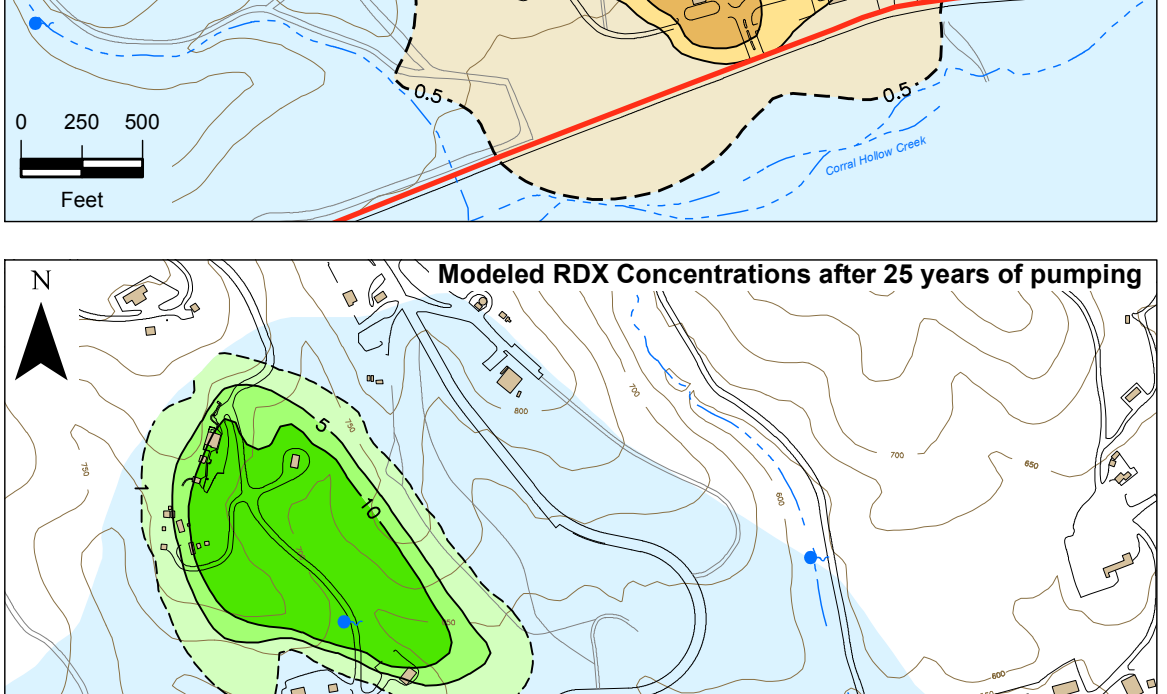
Treatment Facilities and Extraction and Injection Wells (Scenario 1)		
815-SRC:	**815-DSB:**	**817-SRC:**
W-815-02	W-35C-04	W-817-01
W-815-04	W-6ER	*W-817-06A*
W-815-1918	**830-DISS:**	**817-PRX:**
815-PRX:	W-830-2216	W-817-03
W-818-08		*W-817-02*
W-818-09		*W-817-2109*
W-814-2134		



Treatment Facilities and Extraction and Injection Wells (Scenario 2)		
815-SRC:	**815-DSB:**	**817-SRC:**
W-815-2803 (to be drilled)	W-35C-04	W-817-01
W-815-02	W-6ER	*W-817-06A*
W-815-04	W-815-2621 (to be converted)	**817-PRX:**
W-815-1918	W-815-2608 (to be converted)	W-817-03
815-PRX:	**830-DISS:**	*W-817-02*
W-818-08	W-830-2216	*W-817-2109*
W-818-09		
W-814-2134		

Figure A-4. Capture zone analysis results for the a) Scenario 1 "Five-Year Average" and b) Scenario 2 "As Designed" remedial extraction well fields as simulated by the $Tnbs_2$ hydrostratigraphic unit FEFLOW model.

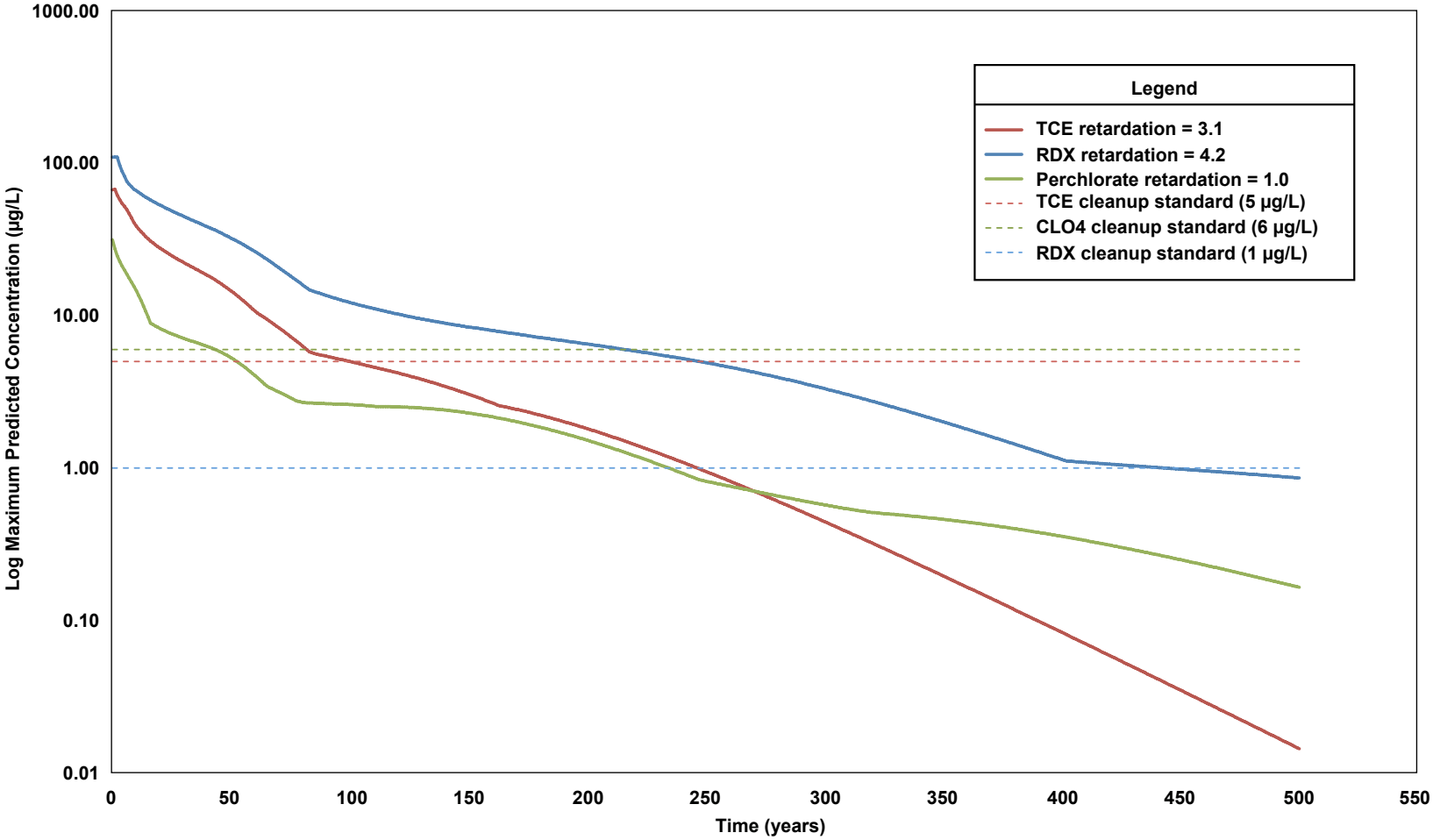




Legend

- Spring
- 0.5 TCE isoconcentration contour (ug/L)
- 5 RDX isoconcentration contour (ug/L)
- 6 Perchlorate isoconcentration contour (ug/L)
- Stream (ephemeral)
- 600 Topographic contour (ft above MSL)
- Paved road
- Dirt road or firetrail
- Site 300 boundary
- Building/structure
- Extent of saturation (2010 Annual)

Figure A-5. TCE, RDX and Perchlorate isoconcentration contours simulated using the $Tnbs_2$ FEFLOW model after 25 years of pumping using the Scenario 2 "As Designed" extraction wellfield.



ERD_S3R_11_0184

Figure A-6. Preliminary maximum TCE, Perchlorate, and RDX concentrations predicted over time in the $Tnbs_2$ HSU with cleanup standards.

Attachment A

High Explosives Process Area

Five-Year Review Inspection Checklist

High Explosives Process Area Operable Unit
Five-Year Review Site Inspection Checklist
Lawrence Livermore National Laboratory (LLNL) Site 300

I. SITE INFORMATION

Site Name: High Explosives Process Area (HEPA) Operable Unit (OU), LLNL Site 300

Date of inspection: March 31, 2011

Location and Region: Corral Hollow Road, San Joaquin/Alameda County, California

EPA Region: 9

EPA ID: CA 2890090002

Agency Leading the Five-Year Review: U.S. Department of Energy (DOE) – Livermore Site Office (LSO)

Weather/Temperature: The climate of Site 300 is semiarid and windy with wide temperature variations.

Remedy Includes:

- Monitoring to evaluate the effectiveness of the remedial action in achieving cleanup standards.
- Risk and hazard management (including institutional and administrative controls) to prevent onsite workers exposure to volatile organic compounds (VOCs) volatilizing from subsurface soil and impacts to animals until risk and hazard is mitigated through active remediation.
- Extracting and treating VOCs, HE compounds, and perchlorate in ground water to mitigate unacceptable VOC inhalation risk for onsite workers, prevent further impacts to ground water and offsite plume migration, and reduce contaminant concentrations in ground water to cleanup standards.
- Monitoring Natural Attenuation (MNA) of nitrate in ground water.

Site Map: See HEPA OU Five-Year Review Figure 1.

II. INTERVIEWS

1. O&M Site Manager

Lawrence Livermore National Security (LLNS), LLC (M&O Contractor to DOE): Leslie Ferry, Site 300 Environmental Restoration (ER) Program Leader.

Remarks: As there is a full-time presence of the DOE-LSO Remedial Project Manager (RPM) and the LLNS Site 300 ER Program Leader, Site 300 ER Field Operations Manager, and the HEPA OU treatment facility operator at the site, the oversight, inspections, evaluations, and discussions of the HEPA OU remedy are ongoing. Remedy performance, facility operations, and any related issues are managed in real-time in collaboration with the Field Operations Manager, the facility operator, and full-time staff from the Site 300 ER Field Operations, Hydrogeology, Engineering, Water Quality Sampling & Analysis Teams. As such, there was no single "interview" of DOE or LLNS O&M Managers or interview results that can be referenced. The information contained within this inspection checksheet is a compilation of this and other DOE-LSO RPM routine inspections, evaluations, and discussions with the LLNS Site 300 ER Program Leader and staff regarding the HEPA OU remedy and treatment facility. In addition, DOE/LLNS presents and discusses any treatment facility operations and maintenance (O&M) or other remedy related issues with the regulatory agencies on an ongoing basis via monthly regulatory RPM project updates and meetings, and in the semi-annual and annual compliance monitoring reports.

2. O&M Staff

Lawrence Livermore National Security (LLNS), LLC (M&O Contractor to DOE):

- Steve Orloff, Site 300 ER Field Operations Manager.
- Larry Griffith, Operator - HEPA ground water extraction and treatment systems.
- David Graves, Operator - HEPA ground water extraction and treatment systems.
- Todd Tramell, Operator - HEPA ground water extraction and treatment systems.

Remarks: As there is a full-time presence of the DOE-LSO RPM, LLNS Site 300 ER Program Leader, Site 300 ER Field Operations Manager, and HEPA OU treatment facility operators at the site, the oversight, inspections, evaluations, and discussions of the HEPA OU remedy are ongoing. Facility operations and any related issues are managed in real-time by the entities listed above in collaboration with full-time staff from the Site 300 ER Field Operations, Hydrogeology, Engineering, Water Quality Sampling & Analysis Teams. As such, there was no single "interview" of O&M staff or interview results that can be referenced. The information contained within this

inspection checksheet is a compilation of this and other DOE-LSO RPM routine inspections, evaluations, and discussions regarding the HEPA OU remedy and treatment facility.

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3. Local Regulatory Authorities and Response Agencies (i.e., State and Tribal offices, emergency response office, police department, office of public health or environmental health, zoning office, recorder of deeds, or other city and county offices, etc.) Fill in all that apply.

Not applicable.

III. ON-SITE DOCUMENTS & RECORDS VERIFIED

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1. O&M Documents

O&M manual:	Readily available and up-to-date
As-built drawings:	Readily available and up-to-date
Maintenance logs:	Readily available and up-to-date

Remarks: As-built drawings for the HEPA OU treatment facilities are maintained in the LLNL Environmental Restoration Department files. The HEPA OU treatment facilities consist of the Building 815-Source (815-SRC), Building 815-Proximal (815-PRX), Building 815-Distal Site Boundary (815-DSB), Building 817-Source (817-SRC), Building 817-Proximal (817-PRX), and Building 829-Source (829-SRC). The HEPA OU treatment facilities maintenance activities are recorded in a facility-specific logbook maintained by the facility operator. In addition, facility maintenance activities are discussed in monthly Project Updates submitted to the regulatory RPMs, at regular RPM meetings, and in the semi-annual and annual Site-Wide Compliance Monitoring Reports.

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2. Site-Specific Health & Safety Plan

Site-Specific Health & Safety Plan:	Readily available and up-to-date
Contingency plan/emergency response plan:	Readily available and up-to-date

Remarks: Site-specific health and safety information for Environmental Restoration activities is contained in the "Site Safety Plan for LLNL CERCLA Investigations at Site 300." Activity-specific hazards and controls are contained in the LLNL Environmental Restoration Integration Work Sheets. Activities conducted at LLNL Site 300 are also conducted in accordance with the LLNL Environment, Safety, and Health Plan.

The contingency plan, including contingency actions in the event of natural disasters or other emergencies, for the HEPA OU remedial action is included in the "Compliance Monitoring Plan and Contingency Plan for the Environmental Restoration at LLNL Site 300."

Emergency responses are also contained in Volume II, Part 22 of the LLNL Environment, Safety, and Health Plan and the Self-Help Plans.

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3. O&M and OSHA Training Records

O&M and OSHA Training Records	Readily available and up-to-date

Remarks: Operation and maintenance activities associated with the HEPA OU ground water extraction and treatment systems are recorded and maintained in the facility-specific logbooks maintained by the facility operators. In addition, O&M activities are discussed in monthly Project Updates submitted to the regulatory RPMs, at regular RPM meetings, and in the semi-annual and annual Site-Wide Compliance Monitoring Reports.

OSHA HAZWOPER training for LLNS ER Department staff is up-to-date. Training Records for LLNS ER Department staff are maintained electronically in the LLNL Laboratory Training Records and Information (LTRAIN) System.

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4. Permits and Service Agreements

Air discharge permit:	Not applicable
Effluent discharge permit:	Not applicable*
Waste Disposal:	Readily available and up-to-date
Other permits:	Not applicable

Remarks:

Air discharge permit: There are no air permits associated with the HEPA OU treatment systems because there is no soil vapor treatment occurring in the OU.

***Effluent discharge:** Effluent discharge limits are contained in the Substantive Requirements for Waste Discharge issued by the Regional Water Quality Control Board (RWQCB)-Central Valley Region and in the Site-Wide Record of Decision (ROD) for LLNL Site 300. The RWQCB Substantive Requirements and Site-Wide ROD are maintained in the administrative record at LLNL; the Site-Wide ROD is also available on-line at www-erd.llnl.gov/library/index.html

Waste Disposal: Spent treatment media is stored at a permitted onsite storage facility (EPA ID No CA2890090002) by the LLNL Radioactive and Hazardous Waste Department prior to shipment offsite to a permitted disposal facility.

Other permits: None.

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5. Gas Generation Records

Gas Generation Records: Not applicable

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6. Settlement Monument Records

Settlement Monument Records: Not applicable

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7. Ground water Monitoring Records

Ground water Monitoring Records: Readily available and up-to-date

Remarks: Ground water monitoring records for the HEPA OU are maintained in the LLNL ER Department's Taurus Environmental Information Management System (TEIMS) database. The ground water compliance monitoring results are presented in the semi-annual and annual Site-Wide Compliance Monitoring Reports that are sent to the U.S. EPA, the RWQCB, and the California Department of Toxic Substances Control (DTSC), and are available on-line at www-erd.llnl.gov/library/index.html

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8. Leachate Extraction Records:

Leachate Extraction Records: Not applicable

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9. Discharge Compliance Records

Air: Not applicable
Water: Readily available and up-to-date

Remarks:
Air: No vapor treatment is performed in the HEPA OU.

Water (effluent): The HEPA OU ground water extraction and treatment systems effluent discharge compliance records are maintained in the LLNL ER Department's TEIMS data base, and are presented in the semi-annual and annual Site-Wide Compliance Monitoring Reports that are sent to the U.S. EPA, the RWQCB, and DTSC, and are available on-line at www-erd.llnl.gov/library/index.html

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10. Daily Access/Security Logs

Daily Access/Security Logs: Readily available and up-to-date

Remarks: The HEPA OU treatment facilities maintenance activities are recorded in a facility-specific logbook maintained by the facility operators. Site 300 is a restricted access facility and badging and clearance that must be presented to a security force guard is required to gain entry to the site.

IV. O&M COSTS

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1. O&M Organization

Contractor for Federal Facility: The Environmental Restoration Department of Lawrence Livermore National Security, LLC; the M&O contractor for the U.S. DOE at LLNL.

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2. O&M Cost Records

O&M Cost Records: Readily available and up-to-date
Funding mechanism in place

Remarks: The actual annual costs for the HEPA OU during the review period (2007-2011) are presented in Table 1 of the Five-Year Review. LLNS Environmental Restoration Department provides monthly reports to the DOE-LSO RPM on HEPA OU restoration planned and actual costs with explanations/justifications of any cost variances.

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3. Unanticipated or Unusually High O&M Costs During the Review Period

Describe costs and reasons: No unanticipated or unusually high O&M costs were incurred during the review period. As described in Table 1 of the HEPA Five-Year Review, costs for the HEPA OU were consistently under budget for the review period due to lower than expected operations, maintenance, and optimization costs.

V. ACCESS AND INSTITUTIONAL CONTROLS — Applicable

A. Fencing

1. Fencing Damaged

Fencing damaged location:	Fencing in good condition
Gate secured:	Yes

Remarks: LLNL Site 300 is a restricted access facility that is surrounded by fencing to prevent unauthorized access.

B. Other Access Restrictions

2. Signs and Other Security Measures

Signs and Other Security Measures In place	Yes

Remarks: LLNL Site 300 is a restricted access facility that is surrounded by fencing and has a full-time security force to prevent unauthorized access to the site.

C. Institutional Controls (ICs)

1. Implementation and Enforcement

Site conditions imply ICs not properly implemented:	No
Site conditions imply ICs not being fully enforced:	No

Type of monitoring (e.g., self-reporting, drive by):	Physical inspection
Frequency:	Physical ICs are inspected annually. ICs are reviewed annually for adequacy and protectiveness.

Responsible party/agency:	U.S DOE
Contact Name:	Claire Holtzapple
Title:	DOE-LSO Site 300 Environmental Restoration RPM
Phone No.:	925/422-0670

IC Inspection Date: November 4, 2010

Reporting is up-to-date:	Yes
Reports are verified by the lead agency:	Yes
Specific requirements in deed or decision document have been met:	Yes
Violations have been reported:	Not Applicable
Other problems or suggestions:	None

Remarks: Refer to Section 4.4. (Institutional Controls) of the HEPA OU Five-Year Review for further details on institutional controls in the HEPA OU.

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2. Adequacy

ICs are adequate: Yes

Remarks: Refer to Section 4.4. (Institutional Controls) of the HEPA Five-Year Review for further details on institutional controls in the HEPA OU.

D. General

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1. Vandalism/trespassing

Vandalism/trespassing: No vandalism evident

Remarks: LLNL Site 300 is a restricted access facility that is surrounded by fencing and has a full-time security force to prevent unauthorized access to the site.

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2. Land Use Changes Onsite

Land Use Changes Onsite: None

Remarks: There have been no changes in land, building, or ground water use in the HEPA OU since the Site-Wide Record of Decision and none are anticipated. Facilities in the HEPA have been in use since the late 1950s for the chemical formulation, mechanical pressing, and machining of HE compounds into shaped detonation devices. At Site 300, ground water is used for a variety of needs including cooling towers, HE processing, and fire suppression. Bottled water is the primary source of onsite drinking water, however potable ground water from onsite water-supply Well 20, located in the HEPA OU, is available as necessary for potable supply. The use of Well 18, also located in the southeast part of the HEPA OU, as a water-supply well was discontinued due to sporadic detections of TCE in samples from this well. Although Well 18 is inactive, it is considered a backup well to supply

water for emergency fire suppression. Site 300 is currently scheduled to transition to Hetch Hetchy water as its primary onsite water supply in 2013. Refer to Section 3.2. (Land and Resource Use) of the HEPA OU Five-Year Review for further details on institutional controls in the HEPA OU.

3. Land Use Changes Offsite

Land Use Changes Offsite: Not applicable

Remarks: Current offsite land use near the OU includes agriculture, private residences, and an ecological preserve. The nearest major population center (Tracy, California) is 8.5 miles to the northeast. While there is offsite development proposed adjacent to and north of Site 300 (the Tracy Hills Development), this development does not border the HEPA OU. There is no known planned modification or proposed development of the offsite land adjacent to the OU. There are private offsite water-supply wells in use near the OU. Refer to Section 3.2. (Land and Resource Use) of the HEPA Five-Year Review for further details on institutional controls in the HEPA OU.

VI. GENERAL SITE CONDITIONS

A. Roads

1. Roads Damaged

Roads damaged location: Roads adequate

Remarks: The HEPA OU treatment facilities and wells are accessed by roads maintained by the LLNL Site 300 management.

B. Other Site Conditions

Remarks: The HEPA OU treatment facilities and wells are maintained in good condition by the LLNL Site 300 management.

VII. LANDFILL COVERS Not applicable

VIII. VERTICAL BARRIER WALLS Not applicable

IX. GROUND WATER/SURFACE WATER REMEDIES Applicable

A. Groundwater Extraction Wells, Pumps, and Pipelines Applicable

1. Pumps, Wellhead Plumbing, and Electrical

Good condition: Yes
All required wells properly operating: Yes

Remarks: The ground water extraction wells are inspected weekly and are in good condition and operating properly.

2. Extraction System Pipelines, Valves, Valve Boxes, and Other Appurtenances

Good condition: Yes

Remarks: All extraction system pipelines and valves are inspected weekly and are in good condition.

3. Spare Parts and Equipment

Readily available: Yes
Good condition: Yes

Remarks: Spare parts for routine equipment maintenance are readily available and in good condition.

B. Surface Water Collection Structures, Pumps, and Pipelines Not applicable

C. Treatment System Applicable

1. Treatment Train (check components that apply)

Metals removal:	Not applicable
Air Stripping:	Not applicable
Oil/Water separation:	Not applicable
Bioremediation:	Not applicable
Carbon adsorbers:	Yes
Filters: Cuno particulate filters:	Yes
Additive (e.g., chelation agent, flocculent):	Not applicable
Good condition:	Yes
Sampling ports properly marked and functional:	Yes
Sampling/maintenance log displayed and up-to-date:	Yes
Equipment properly identified:	Yes
Quantity of ground water treated annually:	3,126,000 gallons
Quantity of surface water treated annually:	Not applicable
Quantity of soil vapor treated annually:	Not applicable

*** Quantities based on 2010 annual totals.**

Remarks: Refer to Section 4.3 (System Operations/Operations and Maintenance of the HEPA OU Five-Year Review for further details about the HEPA OU ground water extraction and treatment systems operations and maintenance. Photographs of the ground water extraction and treatment systems are included in Attachment A.

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2. Electrical Enclosures and Panels (properly rated and functional)

Good condition:	Yes

Remarks: The electrical control panel and enclosure are in good condition, properly rated, and functional.

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3. Tanks, Vaults, Storage Vessels

Good condition:	Not applicable
Proper secondary containment	Not applicable

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4. Discharge Structure and Appurtenances

Good condition: Yes

Remarks: The effluent from HEPA ground water extraction and treatment systems is discharged to infiltration trenches or injection well(s). See table below.

Treatment System	Discharge Method
815-SRC	Reinjection well W-815-1918
815-PRX	Reinjection well W-815-2134
815-DSB	Infiltration trench
817-SRC	Reinjection well W-817-06A
817-PRX	Reinjection wells W-817-2109 and W-817-02
829-SRC	Reinjection well W-829-08

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5. Treatment Buildings Not applicable

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6. Monitoring Wells

Properly secured/locked: Yes
Functioning: Yes
Routinely sampled: Yes
Good condition: Yes
All required wells located: Yes
Needs maintenance: None

Remarks: The current HEPA OU wellfield consists of 10 ground water extraction wells, six ground water injection wells, three water supply wells, and 79 ground water monitor wells. During 2010, ground water monitoring was conducted in accordance with the CMP monitoring requirements with the following exceptions; twenty-nine required analyses were not performed because there was insufficient water in the wells to collect the samples and twenty-two required analyses were not performed due to an inoperable pump.

D. Monitoring Data

1. Monitoring Data

Is routinely submitted on time:	Yes
Is of acceptable quality:	Yes

2. Monitoring data suggests:

Ground water plume is effectively contained:	Yes
Contaminant concentrations are declining:	Yes

Remarks: Refer to Section 7.5.2 (Ground Water Remediation Progress) of the HEPA OU Five-Year Review for further details on the progress of the remedial action at the HEPA OU.

E. Monitored Natural Attenuation

1. Monitoring Wells (natural attenuation remedy)

Properly secured/locked:	Yes
Functioning:	Yes
Routinely sampled:	Yes
Good condition:	Yes
All required wells located:	Yes
Needs maintenance:	None

Remarks: MNA is the remedy for nitrate in the majority of the OU. Samples are collected annually and reported in the Compliance Monitoring Reports.

X. OTHER REMEDIES

Not Applicable

XI. OVERALL OBSERVATIONS

A. Implementation of the Remedy

Begin with a brief statement of what the remedy is to accomplish (i.e., to contain contaminant plume, minimize infiltration and gas emission, etc.). Describe issues and observations relating to whether the remedy is effective and functioning as designed.

The remedy selected for the HEPA OU is intended to contain contaminant sources, prevent further plume migration, remove contaminant mass from the subsurface, reduce contaminant concentrations in ground water to cleanup standards, and mitigate VOC inhalation risk to onsite workers. Refer to Section 4.1 (Remedy Section) for further details on the remedial action objectives of the HEPA OU remedy.

The remedy at the HEPA OU is effective, functioning as designed, and is protective of human health and the environment for the site's industrial land use. Refer to Section 8 (Technical Assessment) and Section 11 (Protectiveness Statement) of the HEPA OU Five-Year Review for further details regarding the remedy effectiveness, functionality, and protectiveness.

No deficiencies in the remedy for the HEPA OU were identified during this evaluation. Refer to Section 9 (Deficiencies) and Section 10 (Recommendations and Follow-up Actions) of the HEPA OU Five-Year Review for further details regarding deficiency conclusions and recommendations for follow-up actions developed as part of the review process.

B. Adequacy of O&M

Describe issues and observations related to the implementation and scope of O&M procedures. In particular, discuss their relationship to the current and long-term protectiveness of the remedy.

There were no issues or observations related to the implementation and scope of operation and maintenance procedures for the HEPA OU ground water extraction and treatment facilities.

C. Early Indicators of Potential Remedy Problems

Describe issues and observations such as unexpected changes in the cost or scope of O&M or a high frequency of unscheduled repairs, that suggest that the protectiveness of the remedy may be compromised in the future.

There were no issues or observations that suggest that the protectiveness of the remedy at the HEPA OU may be compromised in the future. DOE's long-term plans include periodic assessments and upgrades to the HEPA OU ground water extraction and treatment systems to ensure the effectiveness and protectiveness of the remedy.

D. Opportunities for Optimization

Describe possible opportunities for optimization in monitoring tasks or the operation of the remedy.

DOE identified the following opportunities to improve remedy performance:

1. Drill and install one new extraction well (W-815-2803) to increase hydraulic capture and mass removal in the Building 815 source area and to prevent migration of volatile organic compounds (VOCs), high explosive (HE) compounds, and perchlorate in the $Tnbs_2$ hydrostratigraphic unit (HSU). This extraction well will be connected to the Building 815-Source (815-SRC) treatment facility where extracted ground water will be treated. The well is scheduled to be drilled in 2012 and will be connected to 815-SRC in 2014.
2. Convert $Tnbs_2$ HSU monitor well W-815-2608 to an extraction well to increase hydraulic capture and prevent offsite migration of VOCs, and connect it to the 815-Distal Site Boundary (DSB) ground water treatment system for VOC removal. The well is scheduled to be connected to the 815-DSB facility in 2012. $Tnbs_2$ HSU monitor well W-815-2621 will be evaluated to determine its suitability as an extraction well.
3. Drill and install one new monitor well (W-817-2XM1) to monitor HE compounds, perchlorate, and nitrate concentration trends near the 817-SRC treatment facility in the $Tnbs_2$ HSU. The proposed monitor well will assess the effectiveness of the 817-SRC recirculation cell between extraction well W-817-01 and effluent injection well W-817-06A. This well is scheduled to be drilled in 2014.
4. Drill and install one new monitor well (W-815-2XM1) to monitor VOCs, HE compounds, perchlorate, and nitrate concentration trends near the Building 815 source area in the Tpsg-Tps HSU. This well is scheduled to be drilled in 2014.
5. Over the next five-years:
    - Evaluate $Tnbs_2$ HSU well W-817-2609 in the 817-Proximal area by monitoring contaminant concentrations trends in this well and nearby well W-817-03 to determine whether to convert well W-817-2609 to an extraction well.
    - Identify potential locations for two additional effluent injection wells to allow 817-PRX extraction rates to be increased in the $Tnbs_2$ HSU.
6. Operation of and hydraulic capture zones for existing and new extraction wells in the HEPA OU will be evaluated over the next five years and documented in the Annual Compliance Monitoring Reports. Based on this data, DOE/LLNS will pursue opportunities to optimize wellfield operations to maximize contaminant removal as they are identified.

Refer to Section 9 (Recommendations and Follow-up Actions) in the HEPA OU Five-Year Review for further details on DOE recommendations for remedy optimization.

Attachment A

High Explosives Process Area Operable Unit
Five-Year Review Inspection Checklist

Ground water extraction and treatment system photographs

Building 815-Source ground water extraction and treatment system began operation in 2000. Trichloroethene and Research Department Explosive are removed from extracted ground water by aqueous-phase granular activated carbon. Ion-exchange columns remove perchlorate. Nitrate-bearing effluent is discharged into an injection well for *in situ* denitrification.

Building 815-Proximal ground water extraction and treatment system began operation in 2002. Trichloroethene is removed from extracted ground water by aqueous-phase granular activated carbon. Ion-exchange columns remove perchlorate. Nitrate-bearing effluent is discharged into an injection well for *in situ* denitrification.

Building 815-Distal South Boundary ground water extraction and treatment system began operation in 1999. Trichloroethene is removed from extracted ground water by aqueous-phase granular activated carbon. Treated ground water is discharged to the subsurface via an infiltration trench.

Building 817-Source ground water extraction and treatment system began operation in 2003. Ground water is extracted utilizing solar power. Research Department Explosive is removed from extracted ground water by aqueous-phase granular activated carbon. Ion-exchange columns remove perchlorate. Nitrate-bearing effluent is discharged into an injection well for *in situ* denitrification.

Building 817-Proximal ground water extraction and treatment system began operation in 2005. Trichloroethene and Research Department Explosive are removed from extracted ground water by aqueous-phase granular activated carbon. Ion-exchange columns remove perchlorate. Nitrate-bearing effluent is discharged into an injection well for *in situ* denitrification.

Building 829-Source ground water extraction and treatment system began operation in 2005. Ground water is extracted utilizing solar power. Volatile organic compounds are removed from extracted ground water by aqueous-phase granular activated carbon. Ion-exchange columns remove perchlorate and nitrate. Effluent is discharged into an injection well.

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